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Development and Integration of Control System Models Final Report

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1. Summary

The design of a pointing control system requires an iterative procedure that includes mathematical modeling of the multi-body mechanical system, dynamics and control simulation, and performance analysis and evaluation. Since the performance of a pointing control system is determined from the interaction of the control system and the dynamics of the mechanical system, the design of a control system that meets performance requirements depends on how well the dynamics of the mechanical system is understood and can be modeled. Most mechanical systems are comprised of rigid and flexible multibodies dynamic systems that could yield undesirable vibration due to any disturbance and could deteriorate the performances of pointing control systems. Therefore, in order to meet the performance requirements, the control system and mechanical system must interact favorably to suppress these disturbances.

The computer simulation tool, TREETOPS, has been developed and used at MSFC to model these complicated mechanical systems and to perform their dynamics and control analysis with pointing control systems. It has been shown that TREETOPS, in conjunction with various tools of MATLAB, provides an effective approach for the control engineer to model and analyze of pointing control systems through various projects at MSFC. This TREETOPS tool has been used to develop dynamics and control models of the Suppression of Transient Accelerations By Levitation Evaluation (STABLE) and the Active Rack Isolation System (ARIS) projects.

Under this NASA contract, the TREETOPS simulation is being maintained on workstations of ED11, NASA/MSFC and continuously upgraded to account for increasing sophistication of control system missions. A TREETOPS model of Advanced X-ray Astrophysics Facility - Imaging (AXAF-I) dynamics and control system was developed to evaluate the AXAF-I pointing performance for Normal Pointing Mode (NPM). An optical model of the Shooting Star Experiment (SSE) was also developed using the Modeling and Analysis for Controller Optical Systems (MACOS) software developed by JPL. These mathematical models and performance analyses were completed with cooperation of Mr. Mark West and Mr. William Lightsey of NASA/MSFC. The description of the TREETOPS dynamics and control model of AXAF-I and the numerical results of the AXAF-I NPM pointing accuracy and stability analysis are documented in Section 2. The description of MACOS model of the SSE optical system and its optical performance analysis results are documented in Section3.

2. AXAF-I TREETOPS Dynamics and Control Modeling

2.1 Introduction

Advanced X-ray Astrophysics Facility - Imaging (AXAF-I) is being designed and manufactured by TRW under the program management of NASA Marshall Space Flight Center (MSFC) with the flight scheduled in December 1998. This study was done to assist the pointing control analysis team of NASA/MSFC to evaluate the AXAF-I pointing performance.

The objective of this study is to develop a multi-body dynamics and control model of the AXAF-I for TREETOPS simulation to evaluate the AXAF-I pointing performance for the Normal Pointing Mode (NPM). The unfavorable effects on the AXAF-I pointing performance, due to the static and dynamic unbalance of reaction wheels, and possible interaction between the flexible modes of solar arrays and the dynamics of reaction wheels with isolators are also investigated. The TREETOPS model of AXAF-I dynamic system consists of one rigid body spacecraft, the non-rotating masses and the rotating masses of six reaction wheels with their isolators, and two flexible solar arrays.

The modal data of the flexible solar array was generated off-line using NASTRAN simulation with a NASTRAN data of solar array provided by TRW Space and Electronics Group. This modal data is incorporated with the AXAF-I TREETOPS model using TREEFLX simulation. This section describes the details of TREETOPS model of AXAF-I dynamics and pointing control system for Normal Pointing Mode. This section also presents the results of the NPM pointing control analysis obtained from the TREETOPS simulation. The parameters of the NPM pointing control law and the mass properties of AXAF-I observatory including solar arrays, reaction wheels, and isolators are provided by TRW [1]. The AXAF-I NPM PID control law was coded in FORTRAN with the cooperation of Mr. William Lightsey of NASA/MSFC and combined with the AXAF-I TREETOPS dynamics model. For detailed information on the analytical formulation and modeling aspects of TREETOPS and TREEFLX, the reader is referred to the user's guide [2].

2.2 Description of AXAF-I TREETOPS Simulation

A TREETOPS model of AXAF-I dynamics and control system that includes one rigid body spacecraft, six reaction wheels with isolators, two flexible solar arrays, and Normal Pointing Mode (NPM) control is described in this section.

The AXAF-I spacecraft including the telescope, aspect camera and science instruments is modeled as one rigid body with three rotational degrees of freedom (DOF). Two solar

arrays are modeled as flexible bodies using modal data obtained from NASTRAN simulation and fixed to the AXAF-I spacecraft. The AXAF-I has six reaction wheels mounted on the telescope with six isolators to reduce the vibration transferred to the spacecraft. Each reaction wheel isolator (RWI) is modeled as one rigid body connected to the spacecraft using a six DOF hinge with corresponding torsional and linear stiffness. Each reaction wheel (RW) is modeled as two rigid bodies (one non-rotating base rigid body and one rotating rigid body). The non-rotating base body of reaction wheel is assumed to be fixed on the isolator. The rotating bodies of the reaction wheels have one rotational DOF about their spin axes. Therefore, the AXAF-I TREETOPS model consists of total twenty-one bodies with fifty-seven DOFs. The configuration of the AXAF-I TREETOPS model is shown in Figure 2.2-1.

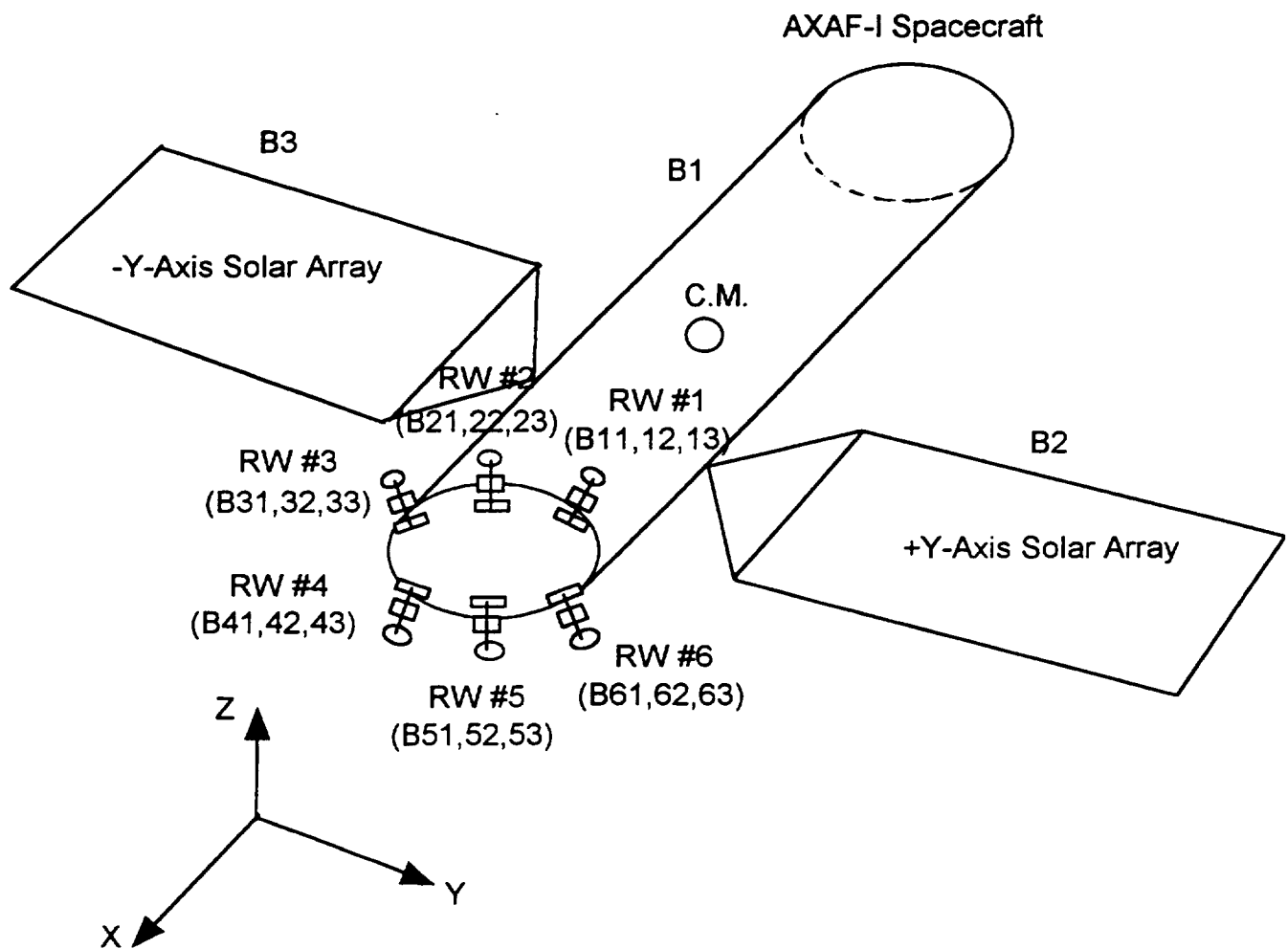


Figure 2.2-1: Configuration of AXAF-I TREETOPS Model

Total mass and moments of inertia of the AXAF-I observatory are available from Reference [1]. Mass properties of the solar arrays were determined from NASTRAN simulation with the NASTRAN model of a solar array provided by TRW. Mass properties of the reaction wheel isolators were also given by TRW. Mass properties of AXAF-I spacecraft were estimated by subtracting mass properties of two solar arrays from total mass properties of the AXAF-I observatory. Mass properties of non-rotating and rotating bodies of the reaction wheels are estimated from the technical data provided by the vendor, TELDIX.

In this study, in order to measure the angular velocity and the attitude angular errors about X, Y, and Z axis of the AXAF-I spacecraft, three ideal TREETOPS Rate Gyro Sensors and one IMU Sensor were used instead of the detailed models and control logic of rate gyros and aspect camera hardware. Also, the detailed control logic of the reaction wheels was not used, but the dynamics of each reaction wheel is determined through TREETOPS simulation with the torques distributed to six reaction wheels by the control torque distribution law. Six reaction wheels are spinning at nominal speeds pointing to the corresponding directions to contribute zero angular momentum to the AXAF-I spacecraft for orbiting equilibrium condition. Each reaction wheel is mounted on its isolator and the direction of the spin axis of reaction wheel is set by connecting the reaction wheel isolator to the AXAF-I spacecraft with the appropriate rotational angle using the TREETOPS Hinge notation.

It should be noted that even though the default printout units are *mks* units in the AXAF-I TREETOPS input file (AXAFI.INT file), Appendix B, the actual units of length, mass, and force used in the AXAF-I TREETOPS model are *ft*, *slug* and *lbf*, respectively. Since the NASTRAN modal output of solar array has units of *inch*, *lbf-sec²/in*, *lbf* for length, mass, and force, respectively, the conversion factors (0.08333, 12, 1) are used for length, mass, and force units used in the AXAF-I TREETOPS model. All rigid bodies excluding the two solar arrays are defined by specifying mass properties (mass and moments of inertia) and nodal points for the center of mass and body connecting points in the local body coordinate system. The two solar arrays are defined in a flexible body modal data file (AXAFI.FLN file) that is created by importing the mass properties, nodal points, and modal data for selected modes (specified in AXAFI.RET file) from the NASTRAN output using TREEFLX. The AXAFI.FLN and AXAFI.RET are in Appendix C and D, respectively. Although all bodies and connecting hinges are defined in their local body coordinate systems, TREETOPS determines the kinematics and dynamics of the AXAF-I observatory in inertia coordinate system using the proper coordinate transformations.

AXAF-I Pointing Control and Aspect Determination (PCAD) flight software has various control modes, however, this study considers only the Normal Pointing Mode (NPM) control. The NPM pointing control logic was coded in FORTRAN in the User Supplied Discrete Controller (USDC) subroutine. The USDC subroutine is in APPENDIX A.

2.2.1 AXAF-I Structural Model

The AXAF-I observatory was modeled as a twenty-one multi-body dynamics system (one rigid body for the spacecraft, two flexible bodies for two solar arrays, six rigid bodies for six reaction wheel isolators, and twelve rigid bodies for six reaction wheels) and all bodies are connected with the same number of hinges according to the tree topology of TREETOPS simulation.

2.2.1.1 AXAF-I Body Models

The AXAF-I TREETOPS rigid body models are defined by providing the input data for the mass properties (total mass and moments of inertia) and the nodal points that correspond to the center of mass, the origin of local body coordinate systems, and hinge connecting points). Two AXAF-I solar arrays are modeled for TREETOPS simulation by converting the NASTRAN modal output to the appropriate format using TREEFLX.

The AXAF-I spacecraft is defined by Body #1 according to the TREETOPS tree topology and assumed to be linked by Hinge #1 with three rotational DOFs to the origin of the inertial coordinate system. For Body #1, twelve nodal points are defined to represent the center of mass (C.M.), the origin of local body coordinate system, two connecting points to two solar arrays, and six connecting points to six reaction wheel isolators. The mass properties of Body #1 were estimated by subtracting mass properties of two solar arrays from total mass properties of AXAF-I observatory.

The positive y-axis flexible solar array of AXAF-I is defined as Body #2 and the negative y-axis flexible solar array is defined as Body #3. A normal modes analysis was done off-line using NASTRAN model of the AXAF-I solar array. The NASTRAN data of the AXAF-I solar array was provided by TRW, Appendix E. The mass properties (mass and moments of inertia) and the output of normal modes analysis of AXAF-I solar array were obtained from NASTRAN and are in Appendix F. In order to define Body #2 and #3 of the AXAF-I TREETOPS model, the NASTRAN output file was assigned to each Body #2 and #3, and then TREEFLX was used to create a AXAFI.FLN file. The AXAFI.FLN file contains the mass properties, selected mode shapes, mode slopes and the coordinates of the selected nodes. For this study ten nodes and first six modes were selected.

The mass properties (Mass, Moment of Inertia about C.M.) and the locations of C.M. of Body #1, #2, #3 used for this study are described in Table 2.2.1.1-1.

Table 2.2.1.1-1: Mass properties and locations of C.M. of AXAF-I Body #1, #2, #3

Body ID	Mass (<i>Slug</i>)	$I_{xx}, I_{yy}, I_{zz}, I_{xy}, I_{xz}, I_{yz}$ (<i>Slug - ft²</i>)	Location of C.M. in inertial coordinates (<i>ft</i>)
1	310.57	5903, 35830, 37314, -94, 737, -89	(31.32, -0.02, 0.09)
2	2.57	141, 11.66, 166.24, 0, 0, 0.17	(37.65, 19.19, 0.05)
3	2.57	141, 11.66, 166.24, 0, 0, 0.17	(37.65, -19.19, 0.05)

The nodes of AXAF-I spacecraft (Body #1) are described in Table 2.2.1.1-2 (B1N2 denotes node #2 of Body #1).

Table 2.2.1.1-2: Nodes Definition of TREETOPS AXAF-I Body #1

Node	Description	Location in body coordinates (<i>ft</i>)
B1N1	C.M. of Body #1	(31.32, -0.02, 0.09)
B1N2	Origin of Body #1 coordinate	(0,0,0)
B1N3	Attaching point of #1 reaction wheel isolator	(40.08, 2.70, -2.70)
B1N4	Attaching point of #2 reaction wheel isolator	(38.79, 2.70, -2.70)
B1N5	Attaching point of #3 reaction wheel isolator	(37.51, 2.70, -2.70)
B1N6	Attaching point of #4 reaction wheel isolator	(40.08, -2.70, -2.70)
B1N7	Attaching point of #5 reaction wheel isolator	(38.79, -2.70, -2.70)
B1N8	Attaching point of #6 reaction wheel isolator	(37.51, -2.70, -2.70)
B1N9	Attaching point of +Y-axis solar array	(37.65, 4.94, 0)
B1N10	Attaching point of -Y-axis solar array	(37.65, -4.94, 0)
B1N11	Attaching point of IRU A	(31, 2.12, 2.63)
B1N12	Attaching point of IRU B	(31.28, 3.28, 1.98)

Since AXAF-I +Y-axis solar array (Body #2) and -Y-axis solar array (Body #3) have same mass properties and configuration, the NASTRAN modal output of either one of solar arrays can be used for both Body #2 and #3. The nodes of Body #2 and #3 are asymmetric about X-axis and described with the external and internal NASTRAN Grid ID numbers in Table 2.2.1.1-3.

Table 2.2.1.1-3: Nodes Definition of TREETOPS AXAF-I Body #2 and #3

TREETOPS Node #	NASTRAN internal Grid ID #	NASTRAN external Grid ID #	Location in body coordinates (ft)
B2N2, B3N2	72	63001	(0, 0, 0)
B2N3, B3N3	50	60000	(3.36, 4.70, 0.06)
B2N4, B3N4	54	60003	(-3.36, 4.70, 0.06)
B2N5, B3N5	30	60400	(3.36, 12.00, 0.06)
B2N6, B3N6	34	60403	(-3.36, 12.00, 0.06)
B2N7, B3N7	10	60800	(3.36, 19.30, 0.06)
B2N8, B3N8	14	60803	(-3.36, 19.30, 0.06)
B2N9, B3N9	1	61100	(3.36, 26.26, 0.06)
B2N10, B3N10	4	61103	(-3.36, 26.26, 0.06)

Six reaction wheels are mounted on their isolators that are fixed to Body #1 with their spin directions shown in Figure 2.2.1.1-1 [1]. Each isolator of reaction wheels #1, #2, #3, #4, #5, and #6 was respectively defined by Body #11, #21, #31, #41, #51, #61. These RW isolators are linked to the corresponding attaching nodes of Body #1 by Hinge #11, #21, #31, #41, #51, #61. Each hinge has three rotational and three translational DOFs with appropriate stiffness.

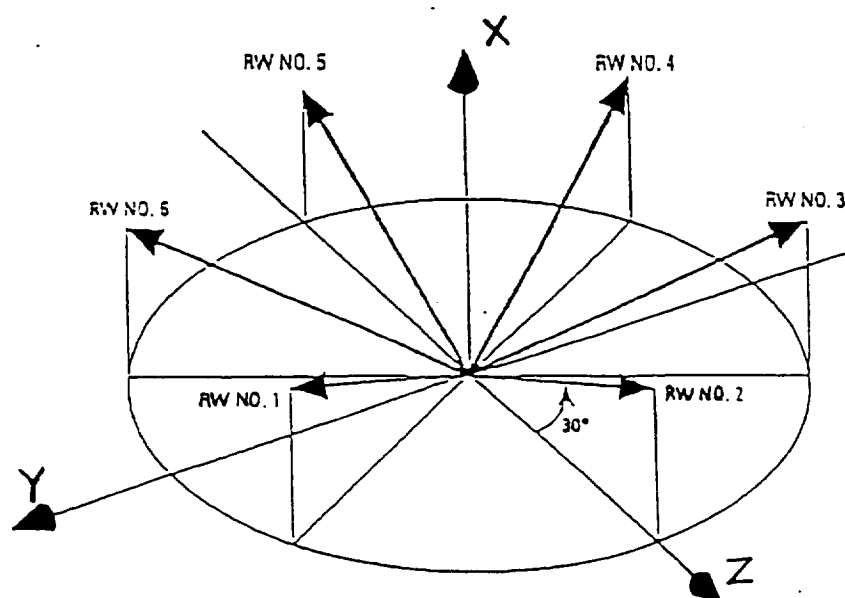


Figure 2.2.1.1-1: AXAF-I RW Positive Spin Vectors Relative to Body #1 Coordinates

Each reaction wheel was modeled as two rigid body dynamics systems (one non-rotating base rigid body and one rotating rigid body). Each non-rotating rigid body of reaction wheels #1, #2, #3, #4, #5, and #6 was respectively defined by Body #12, #22, #32, #42, #52, #62 and assumed to be fixed to the its isolator by defining Hinges #12, #22, #32, #42, #52, #62 with zero DOF. Also, each rotating rigid body of reaction wheels #1, #2, #3, #4, #5, and #6 was respectively defined by Body #13, #23, #33, #43, #53, #63 and linked to its corresponding non-rotating rigid body by Hinge #13, #23, #33, #43, #53, #63. The mass properties (Mass, Moment of Inertia about C.M.) of the reaction wheel isolators and the reaction wheels used for this study are described in Table 2.2.1.1-4.

Table 2.2.1.1-4: Mass properties of reaction wheels and isolators

Body	Mass (Slug)	$I_{xx}, I_{yy}, I_{zz}, I_{xy}, I_{xz}, I_{yz}$ (Slug - ft ²)
Reaction wheel isolator (Body #11, #21, #31, #41, #51, #61)	0.23	1.54E-2, 1.54E-2, 2.36E-2, 0, 0, 0
Non-rotating body of reaction wheel (Body #12, #22, #32, #42, #52, #62)	0.1823	1.475E-2, 1.475E-2, 2.2125E-2, 0, 0, 0
Rotating body of reaction wheel (Body #13, #23, #33, #43, #53, #63)	0.3659	0.03961, 0.03961, 0.07921, 0, 0, 1E-6

For each reaction wheel isolator and reaction wheel, two nodal points are defined with respect to each body's coordinate system to represent the center of mass, the origin of local coordinate system. Table 2.2.1.1-5 summarized the nodes of the reaction wheel isolators (Body #11, #21, #31, #41, #51, #61), the non-rotating bodies of reaction wheels (Body #12, #22, #32, #42, #52, #62), and the rotating bodies of reaction wheels (Body #13, #23, #33, #43, #53, #63). The unbalance of reaction wheels was defined by specifying non-zero products of inertia and the C.M. offset of the rotating bodies of the reaction wheels as shown in Table 2.2.1.1-4 and Table 2.2.1.1-5.

Table 2.2.1.1-5: Nodes Definition of TREETOPS AXAF-I Reaction Wheel Isolators and Non-Rotating and Rotating bodies of Reaction Wheels

Body	Node	Description	Location in body coordinates (ft)
B11,21,31,41,51,61	N1	Center of Mass	(0,0,0)
B11,21,31,41,51,61	N2	Origin of each body coordinate	(0,0,0)
B12,22,32,42,52,62	N1	Center of Mass	(0,0,0.1936)
B12,22,32,42,52,62	N2	Origin of each body coordinate	(0,0,0)
B13,23,33,43,53,63	N1	Center of Mass	(0,-5E-6,0)
B13,23,33,43,53,63	N2	Origin of each body coordinate	(0,0,0)

2.2.1.2 AXAF-I Hinge Models

According to the tree topology of TREETOPS modeling, the number of hinges that connects neighboring bodies must be equal to total number of bodies. Therefore, AXAF-I TREETOPS model has twenty-one hinges and each hinge defines nodal points of two connecting bodies, the relationship of each body's coordinate system and DOFs of relative motion between two bodies. The definitions of all hinges of AXAF-I TREETOPS model are summarized in Table 2.2.1.2-1.

Table 2.2.1.2-1: Hinges Definition of AXAF-I TREETOPS Model

Hinge	Connecting nodes	No. of DOF	L1_in - L1_out	L3_in - L3_out
1	B0N0 - B1N1	3 RDOF	(1,0,0) - (1,0,0)	(0,0,1) - (0,0,1)
2	B1N9 - B2N2	0 DOF	(0,1,0) - (0,1,0)	(1,0,0) - (1,0,0)
3	B1N10 - B3N2	0 DOF	(0,-1,0) - (0,1,0)	(1,0,0) - (1,0,0)
11	B1N3 -B11N1	3 RDOF, 3 TDOF	(0.5,0.75,0.4330127) - (0,0,1)	(0.8660254,-0.4330127, -0.25) - (0,1,0)
12	B11N2 - B12N2	0 DOF	(0,0,1) - (0,0,1)	(0,1,0) - (0,1,0)
13	B12N1 - B13N1	1 RDOF	(0,0,1) - (0,0,1)	(0,1,0) - (0,1,0)
21	B1N4 -B21N1	3 RDOF, 3 TDOF	(0.5,0,0.8660254) - (0,0,1)	(0.8660254,0,-0.5) - (0,1,0)
22	B21N2 - B22N2	0 DOF	(0,0,1) - (0,0,1)	(0,1,0) - (0,1,0)
23	B22N1 - B23N1	1 RDOF	(0,0,1) - (0,0,1)	(0,1,0) - (0,1,0)
31	B1N5 -B31N1	3 RDOF, 3 TDOF	(0.5,-0.75,0.4330127) - (0,0,1)	(0.8660254,0.4330127, -0.25) - (0,1,0)
32	B31N2 - B32N2	0 DOF	(0,0,1) - (0,0,1)	(0,1,0) - (0,1,0)
33	B32N1 - B33N1	1 RDOF	(0,0,1) - (0,0,1)	(0,1,0) - (0,1,0)
41	B1N6 -B41N1	3 RDOF, 3 TDOF	(0.5,-0.75,- 0.4330127) - (0,0,1)	(0.8660254,0.4330127, 0.25) - (0,1,0)
42	B41N2 - B42N2	0 DOF	(0,0,1) - (0,0,1)	(0,1,0) - (0,1,0)
43	B42N1 - B43N1	1 RDOF	(0,0,1) - (0,0,1)	(0,1,0) - (0,1,0)
51	B1N7 -B51N1	3 RDOF, 3 TDOF	(0.5,0,-0.8660254) - (0,0,1)	(0.8660254,0,0.5) - (0,1,0)
52	B51N2 - B52N2	0 DOF	(0,0,1) - (0,0,1)	(0,1,0) - (0,1,0)
53	B52N1 - B53N1	1 RDOF	(0,0,1) - (0,0,1)	(0,1,0) - (0,1,0)
61	B1N8 -B61N1	3 RDOF, 3 TDOF	(0.5,0.75,-0.4330127) - (0,0,1)	(0.8660254,-0.4330127, 0.25) - (0,1,0)
62	B61N2 - B62N2	0 DOF	(0,0,1) - (0,0,1)	(0,1,0) - (0,1,0)
63	B62N1 - B63N1	1 RDOF	(0,0,1) - (0,0,1)	(0,1,0) - (0,1,0)

The Hinges between Body #1 and six reaction wheel isolators (HI #11, #21, #31, #41, #51, #61) have 204.5 *lb-ft/rad* of rotational stiffness and 0.362 *lb-ft/rad/sec* of rotational damping and also, 2121.3 *lb/ft* of translational stiffness and 3.75 *lb/ft/sec* of translational damping. For nominal equilibrium condition, reaction wheels #1, #3, #5 have positive 2250 *rpm* of rotational speed and reaction wheels #2, #4, #6 have negative 2250 *rpm* of rotational speed resulting in zero sum of angular momentum to Body #1. The Hinges for spin axes of six reaction wheels (HI #13, #23, #33, #43, #53, #63) have zero rotational stiffness with initial 2250 *rpm* of angular velocities.

2.2.2 AXAF-I TREETOPS Sensor and Actuator Models

For the NPM pointing control of AXAF-I spacecraft, the angular attitude and angular velocity errors of AXAF-I spacecraft are measured and fed back to a PID controller to determine the control torque to obtain the desired pointing accuracy. AXAF-I has two Inertial Reference Unit (IRU) boxes and each IRU has two rate gyros. Since one gyro measures the angular velocities about two axis, total eight angular velocity measurements are available from two IRU boxes. Therefore, the angular velocity at the C.M. of AXAF-I spacecraft can be determined by transferring the eight angular velocity measurements of the two IRUs to the C.M. of AXAF-I spacecraft. AXAF-I has an Aspect Camera that measures the position of the selected Stars to determine the angular attitude error of the AXAF-I spacecraft. The AXAF-I flight software estimates the attitude errors and gyro drift errors of the AXAF-I spacecraft by processing the outputs of the rate gyros and the aspect camera with an attitude and aspect determination algorithm.

In this study, the detailed models of the IRUs, the aspect camera, and the attitude and aspect determination algorithm are not included. Instead, only functional outputs of these hardware sensors are obtained from the ideal TREETOPS sensor models. For the AXAF-I TREETOPS simulation, three ideal TREETOPS Rate Gyros are used to measure three angular velocities of the AXAF-I spacecraft about X, Y, Z axes and one TREETOPS IMU sensor is used to measure three rotational angles of the AXAF-I spacecraft with respect to the inertial coordinates. Three TREETOPS Integrating Gyros are attached on the C.M. of AXAF-I spacecraft to measure the integrals of the angular rate outputs of Rate Gyros. The descriptions of AXAF-I TREETOPS sensors are summarized in Table 2.2.2-1.

Table 2.2.2-1: Definition of TREETOPS AXAF-I Sensors Model

Sensor ID	Type	Attached node	Direction	Description
1	IMU Sensor	B1N1	(1,0,0),(0,1,0),(0,0,1)	Euler angles w.r.t. inertial frame
11	Integrating Gyro	B1N1	(1,0,0)	$\int \omega_x$
12	Integrating Gyro	B1N1	(0,1,0)	$\int \omega_y$
13	Integrating Gyro	B1N1	(0,0,1)	$\int \omega_z$
14	Rate Gyro	B1N1	(1,0,0)	ω_x
15	Rate Gyro	B1N1	(0,1,0)	ω_y
16	Rate Gyro	B1N1	(0,0,1)	ω_z

The AXAF-I has six reaction wheels to generate the control torque to compensate the attitude and angular velocity errors of the spacecraft under NPM control. The control torque at the C.M. of the spacecraft is determined from the AXAF-I NPM control law and distributed to six reaction wheels according to the RW steering law. For the AXAF-I TREETOPS simulation, six TREETOPS Torque actuators are mounted along the spin axes of the six hinges between the non-rotating and rotating bodies of the six reaction wheels. The inputs to these actuators are to be determined by the AXAF-I NPM control law defined in the USDC subroutine in Appendix A. The TREETOPS actuators for AXAF-I are described in Table 2.2.2-2.

Table 2.2.2-2: Definition of TREETOPS AXAF-I Actuators Model

Actuator ID	Type	Acting Node	Description
13	Torque Motor	Hinge 13	Torque about the spin axis of RW #1
23	Torque Motor	Hinge 23	Torque about the spin axis of RW #2
33	Torque Motor	Hinge 33	Torque about the spin axis of RW #3
43	Torque Motor	Hinge 43	Torque about the spin axis of RW #4
53	Torque Motor	Hinge 53	Torque about the spin axis of RW #5
63	Torque Motor	Hinge 63	Torque about the spin axis of RW #6

2.2.3 AXAF-I NPM Control Law Model

The AXAF-I Normal Point Mode (NPM) control is designed to point the telescope at the science target with the required pointing accuracy and stability after the Normal Maneuver Mode (NMM) control acquires the acquisition stars within the allowable error. The AXAF-I flight software uses a Proportional-Integral-Derivative (PID) control law for the NPM pointing control of the spacecraft. The requirements of the NPM control law are given in Table 2.2.3-1 [1].

Table 2.2.3-1: Requirements of the AXAF-I NPM control law

Description	Requirement
Attitude Control Error (arcsec, 1σ , per axis)	4.0
Attitude Control Stability (arcsec, rms per axis, 95% of all 10-second intervals)	0.120
Period of not requiring pointing and stability after completion of momentum unloading	15 minutes

For the AXAF-I TREETOPS simulation, the NPM control law and control parameters that were developed by TRW are combined with the AXAF-I TREETOPS dynamics model. The hierarchy of AXAF-I TREETOPS dynamics and NPM control model is shown in Figure 2.2.3-1.

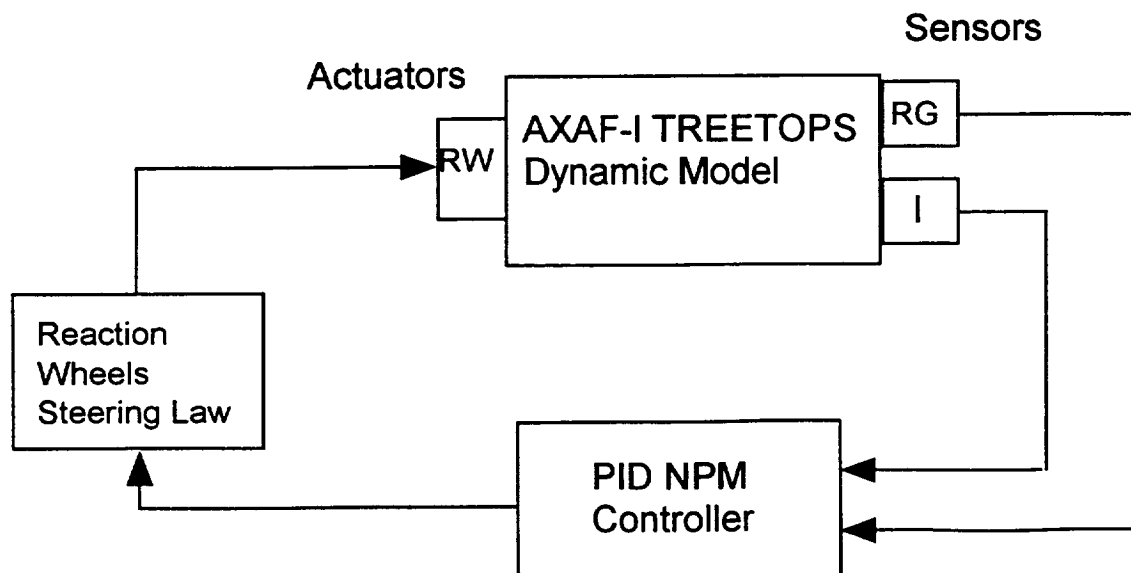


Figure 2.2.3-1: AXAF-I TREETOPS Dynamics and NPM Control Model Layout

The NPM PID control law has about 0.01 Hz of control bandwidth for roll motion and about 0.03 Hz of control bandwidth for pitch and yaw motions. The block diagram of AXAF-I NPM PID control law is shown in Figure 2.2.3-2 [1].

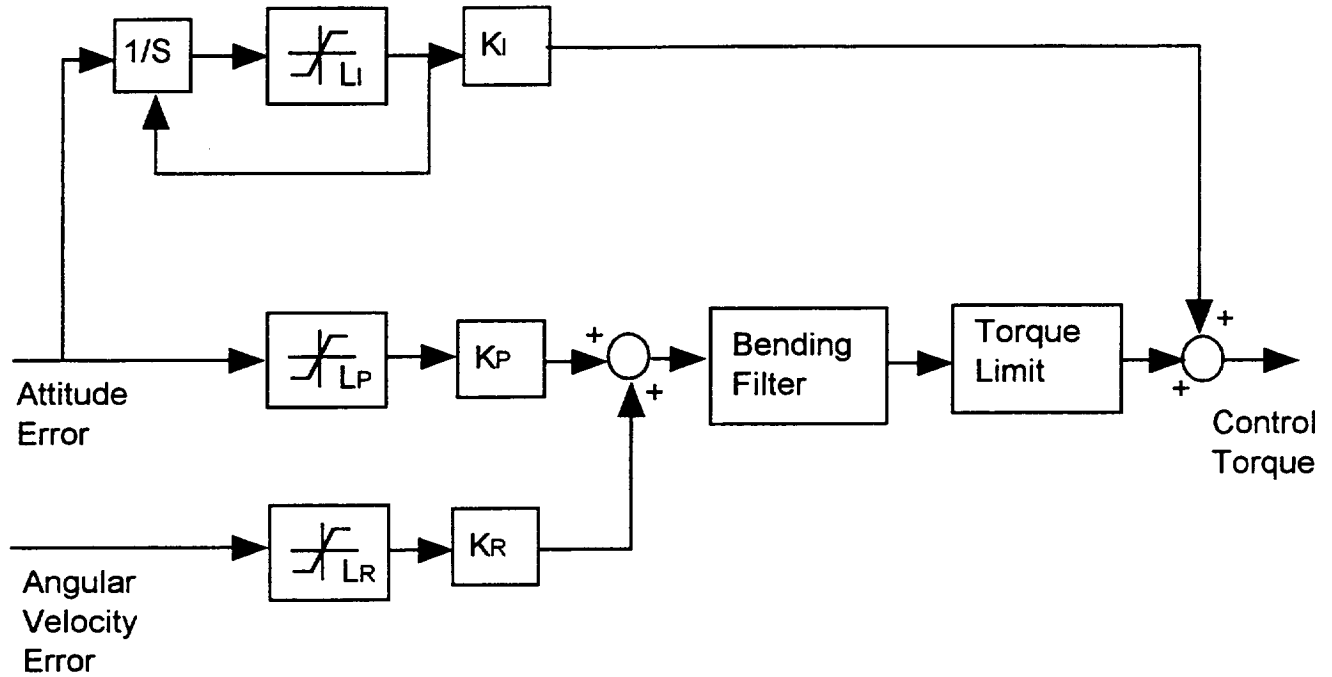


Figure 2.2.3-2: Block Diagram of AXAF-I NPM PID Control Law

The AXAF-I has six reaction wheels in a pyramidal configuration shown in Figure 2.2.1.1-1. The total torque acting on the C.M. of the spacecraft by the six reaction wheels are given by the following equation

$$T_{sc} = B T_w$$

where $T_{sc} = [T_x, T_y, T_z]^T$ is the torque about X, Y, Z axis on the C.M. of the spacecraft in the inertial coordinates and $T_w = [T_1, T_2, \dots, T_6]^T$ is the torque on the six reaction wheels.

The transfer matrix, B consists of six columns that are the unit vectors of the spin axes of the six reaction wheels and is given by

$$B = \begin{bmatrix} 0.5 & 0.5 & 0.5 & 0.5 & 0.5 & 0.5 \\ 0.75 & 0.0 & -0.75 & -0.75 & 0.0 & 0.75 \\ 0.433 & 0.866 & 0.433 & -0.433 & -0.866 & -0.433 \end{bmatrix}$$

For the AXAF-I TREETOPS NPM control simulation, the attitude errors and angular velocity errors of the AXAF-I spacecraft are obtained from the outputs of one TREETOPS IRU sensor and three TREETOPS Rate Gyro sensors. The AXAF-I NPM control law determines the control torque, T on the C.M. of the spacecraft to compensate for attitude errors and angular velocity errors. This control torque, T is opposite to the total torque acting on the spacecraft due to the six reaction wheels, T_{sc} . Once the required control torque, T is calculated by the AXAF-I NPM PID control law, the control torque on each reaction wheel is determined using the following pseudo-inverse steering law which provides the inputs to the AXAF-I TREETOPS Torque actuators.

$$T_w = D T$$

The steering matrix, D is the negative pseudo-inverse matrix of B and is given by

$$D = - \begin{bmatrix} 0.3333 & 0.3333 & 0.1925 \\ 0.3333 & 0 & 0.3849 \\ 0.3333 & -0.3333 & 0.1925 \\ 0.3333 & -0.3333 & -0.1925 \\ 0.3333 & 0 & -0.3849 \\ 0.3333 & 0.3333 & -0.1925 \end{bmatrix}$$

The AXAF-I NPM PID control law and the reaction wheel steering law were coded in the FOTRAN subroutine USDC, Appendix A. The parameters of AXAF-I NPM PID control law are summarized in Table 2.2.3-2.

Table 2.2.3-2: AXAF-I NPM PID Control Law Parameters

Control Parameters	Roll (X)	Pitch (Y)	Yaw (Z)
Proportional gain, K_P ($ft-lb/rad$)	6.506	68.382	72.908
Rate gain, K_R ($ft-lb/rad/sec$)	325.3	3419.1	3645.4
Integral gain, K_I ($ft-lb/rad-sec$)	6.506E-3	3.4191E-2	3.6454E-2
Bending filter, $\frac{a_0 + a_1 Z^{-1} + a_2 Z^{-2}}{1 + a_3 Z^{-1} + a_4 Z^{-2}}$	$a_0 = 7.94213E-5$ $a_1 = 1.588426E-4$ $a_2 = 7.94213E-5$ $a_3 = -1.978409$ $a_4 = 0.978726$	$a_0 = 9.79132E-4$ $a_1 = 1.958264E-3$ $a_2 = 9.79132E-4$ $a_3 = -1.910409$ $a_4 = 0.914326$	$a_0 = 9.79132E-4$ $a_1 = 1.958264E-3$ $a_2 = 9.79132E-4$ $a_3 = -1.910409$ $a_4 = 0.914326$
Position limit, L_P (rad)	0.05695	6.98E-4	6.98E-4
Integral limit, L_I ($rad-sec$)	0.06	0.011	0.01
Rate limit, L_R (rad/sec)	1E6	1E6	1E6
Body torque command limit, T_L ($ft-lb$)	0.25	0.25	0.25

2.3 AXAF-I TREETOPS Simulation Results

The NPM control mode is activated to achieve the required pointing accuracy and stability after the Normal Maneuver Mode (NMM) controller slews the AXAF-I to acquire acquisition stars with the allowable error (less than 100 *arcsec* per axis, 3-sigma). This subsection describes numerical results of AXAF-I NPM pointing control analysis from the TREETOPS simulation. The input files of AXAF-I TREETOPS simulation are in Appendix B, C and D. For the evaluation of the NPM pointing accuracy and stability of AXAF-I, a transient response analysis is performed with initial 100 *arcsec* of pitch (Y-axis) and yaw (Z-axis) attitude errors and initial 2.88 *arcsec/sec* of pitch and yaw angular velocity errors using TREETOPS simulation. These initial errors are defined in the input data of Hinge #1 of the AXAF-I TREETOPS model. The numerical results of the transient response analysis with initial attitude and angular velocity errors are shown in Figure 2.3.1-1 through Figure 2.3.1-4.

Figure 2.3.1-1 shows the attitude and angular velocity errors of AXAF-I spacecraft under NPM control when the initial attitude and angular velocity errors of the spacecraft are given. It is noticed that the initial 100 *arcsec* of pitch and yaw attitude errors are reduced to about 0.75 *arcsec* in 500 seconds under NPM control thus satisfying the AXAF-I pointing accuracy requirement. It is also noticed that the changes of the pitch and yaw attitude are less than 0.01 *arcsec* for 10 seconds in 500 seconds thus satisfying the AXAF-I pointing stability requirement.

In Figure 2.3.1-2 the control torque on six reaction wheels required to correct the 100 *arcsec* of pitch and yaw attitude errors and 2.88 *arcsec/sec* of pitch and yaw angular velocity errors of AXAF-I spacecraft are plotted. Maximum torque of 0.043 *ft-lb* is loaded on reaction wheel #1. It is noted that the actual torque limit of reaction wheel hardware is about 0.1 *ft-lb*.

Figure 2.3.1-3 shows the spin speed changes of six reaction wheels from the nominal wheel speeds (± 2250 rpm) under NPM control when the initial attitude and angular velocity errors of the spacecraft are given. The spin speeds of reaction wheels #1, #2, #3, #4, #5, #6 are changed by 34, 24, -7, -34, -24, 7 rpm, respectively to compensate for the angular momentum due to the initial angular velocity errors.

Figure 2.3.1-4 shows the rotational angle about x-axis and the nutational angles (about y- and z-axis) of the reaction wheel isolator #1 due to the static and dynamic unbalance of the reaction wheel #1. From Figure 2.3.1-4 the amplitude of nutational angles is about 45 *arcsec* and these angles contribute to the misalignment error of the spin axis direction of reaction wheel.

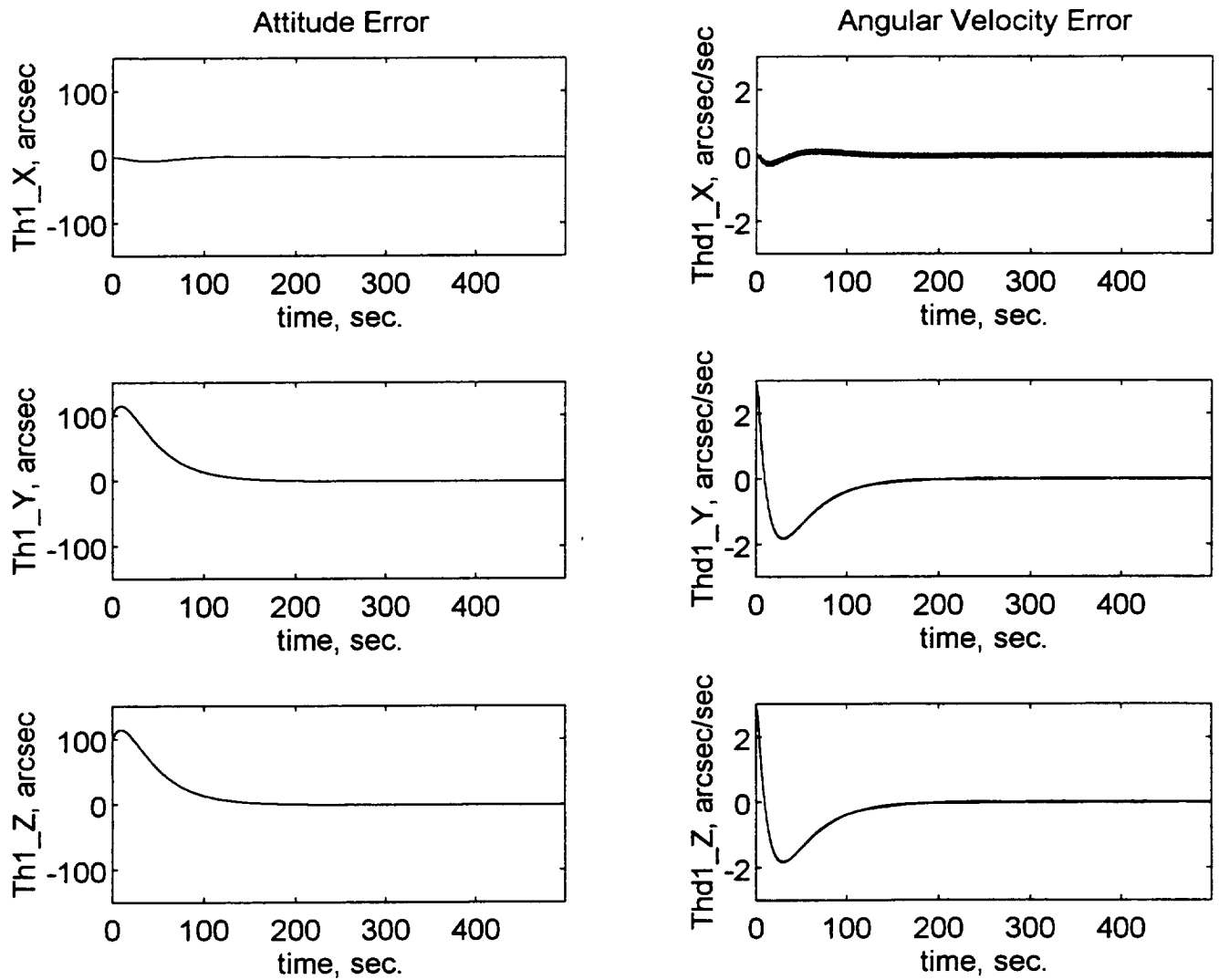


Figure 2.3.1-1: Attitude and Angular Velocity Errors of AXAF-I Spacecraft under NPM Control with Initial Errors

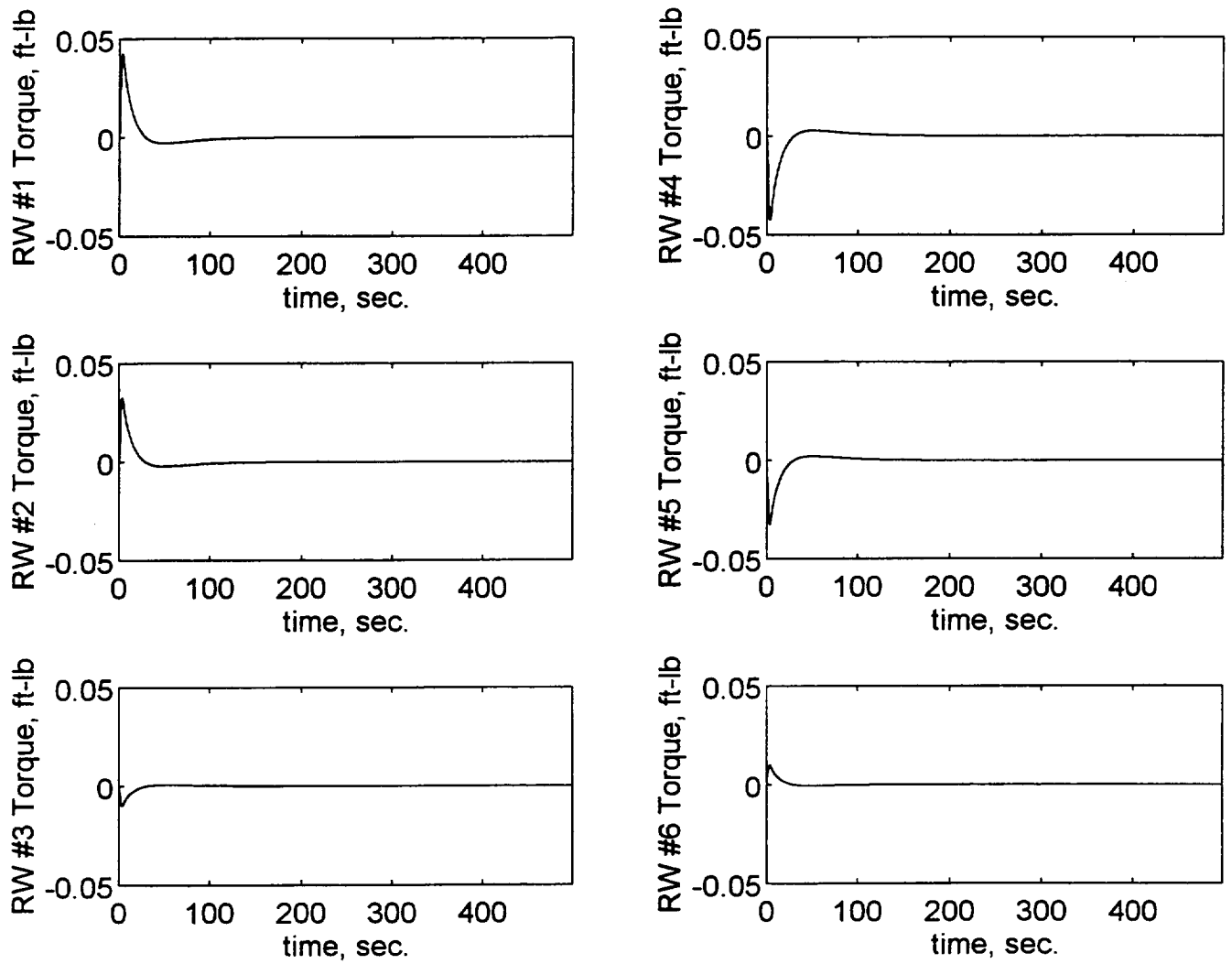


Figure 2.3.1-2: Control Torque on Six Reaction Wheels
under NPM Control with Initial Errors

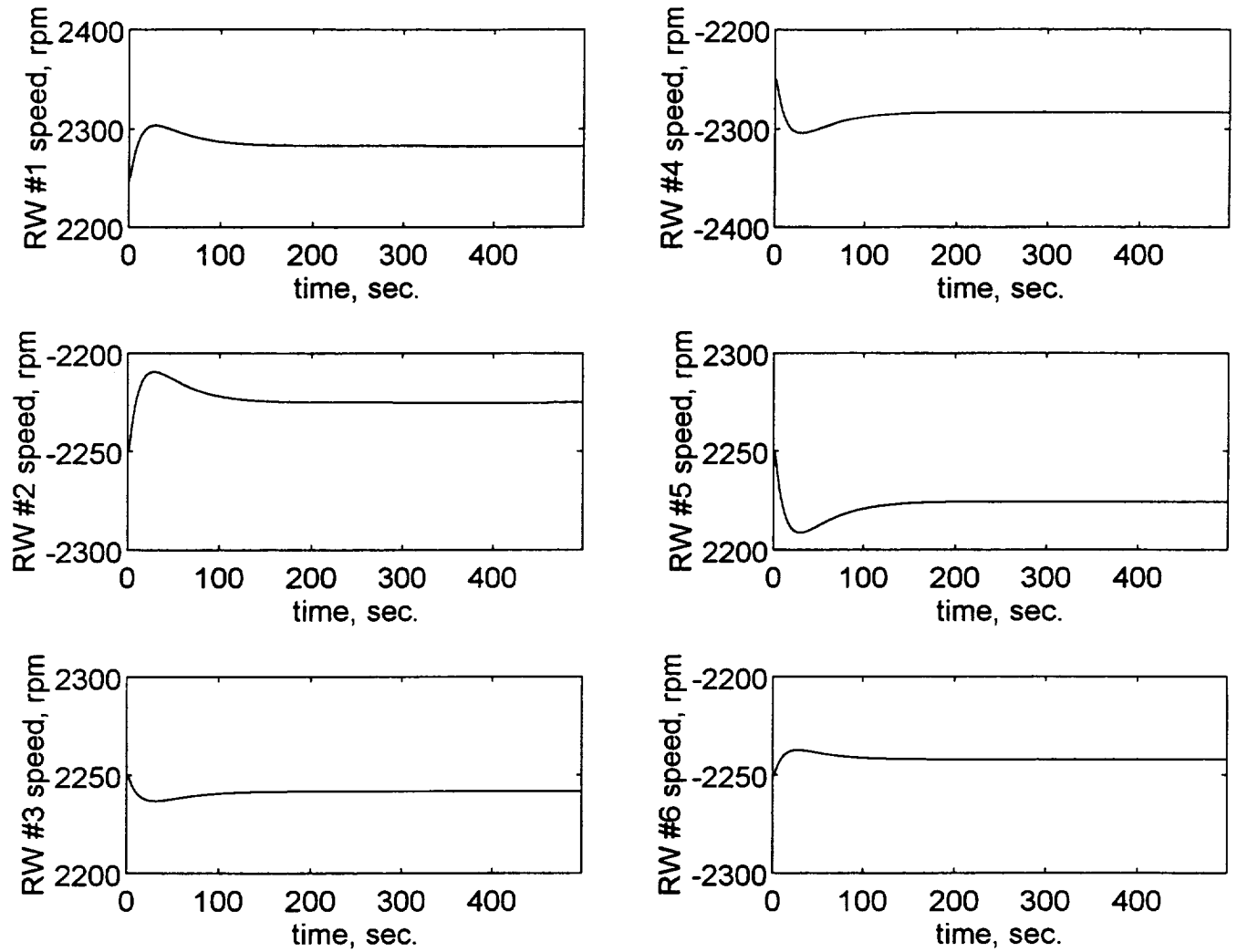


Figure 2.3.1-3: Spin Speeds of Six Reaction Wheels
under NPM Control with Initial Errors

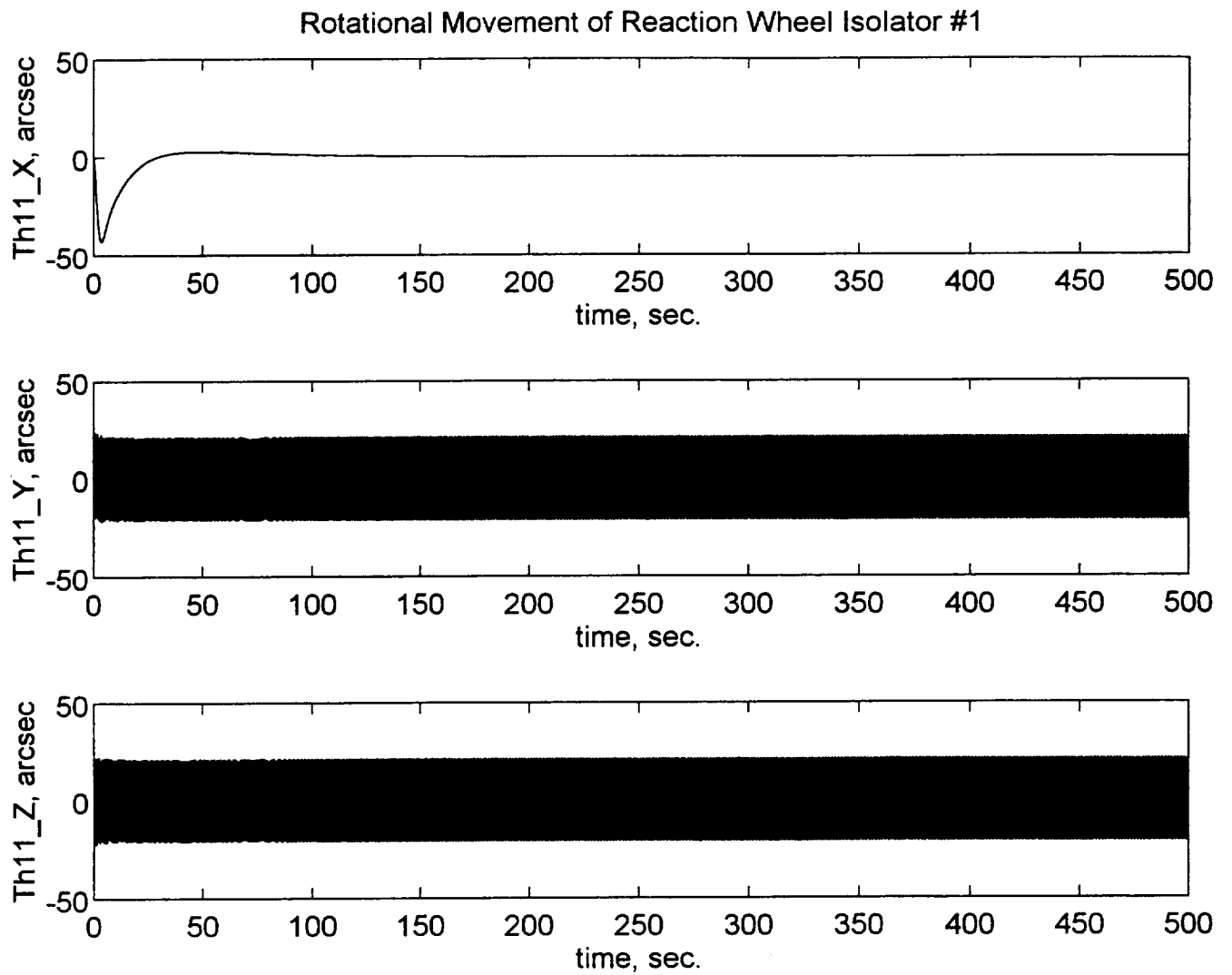


Figure 2.3.1-4 Angular movement of Reaction Wheel #1
under NPM Control with Initial Errors

2.4 Conclusion

A TREETOPS multi-body dynamics and control model of AXAF-I observatory was developed for NPM pointing control and documented in Section 1. The NPM pointing accuracy and stability of AXAF-I was evaluated from the numerical results of transient response analysis with initial attitude and angular velocity errors.

The simulation results indicated that the the pointing accuracy and stability requirements of AXAF-I could be met for the NPM operation. Possibly unfavorable effects on the pointing performance of AXAF-I due to the interaction between the dynamics of reaction wheels and the flexible solar arrays are negligible. It is noticed that there are two nutational modes (one increasing frequency and another decreasing frequency) for each reaction wheel isolator due to the gyroscopic effects of the spinning unbalanced reaction wheel. The effect of unbalanced reaction wheels, specified in Subsection 2.2.1.1, on the pointing performance of AXAF-I was insignificant for the NPM operation.

This study incorporated the simplified NPM pointing control logic with the ideal sensors of attitude and angular velocity errors in AXAF-I multi-body dynamics model for TREETOPS simulation. Additional studies, which include the detailed flight software control logic of AXAF-I pointing control and aspect determination with various control modes, are needed to evaluate in greater depth the pointing performance of AXAF-I on orbit.

2.5 References

- [1] "AXAF-I Pointing Control and Aspect Determination Subsystem Critical Design Audit Volume 1- Subsystem Analyses," TRW-SE 11K, TRW Space & Electronics Group, January 1996.
- [2] "User's Manual for TREETOPS, A Control System Simulation for Structures With a Tree Topology," NASA Contract NAS-36287, Marshall Space Flight Center, April 1990.

3. Optical Modeling and Analysis of SSE Optical System

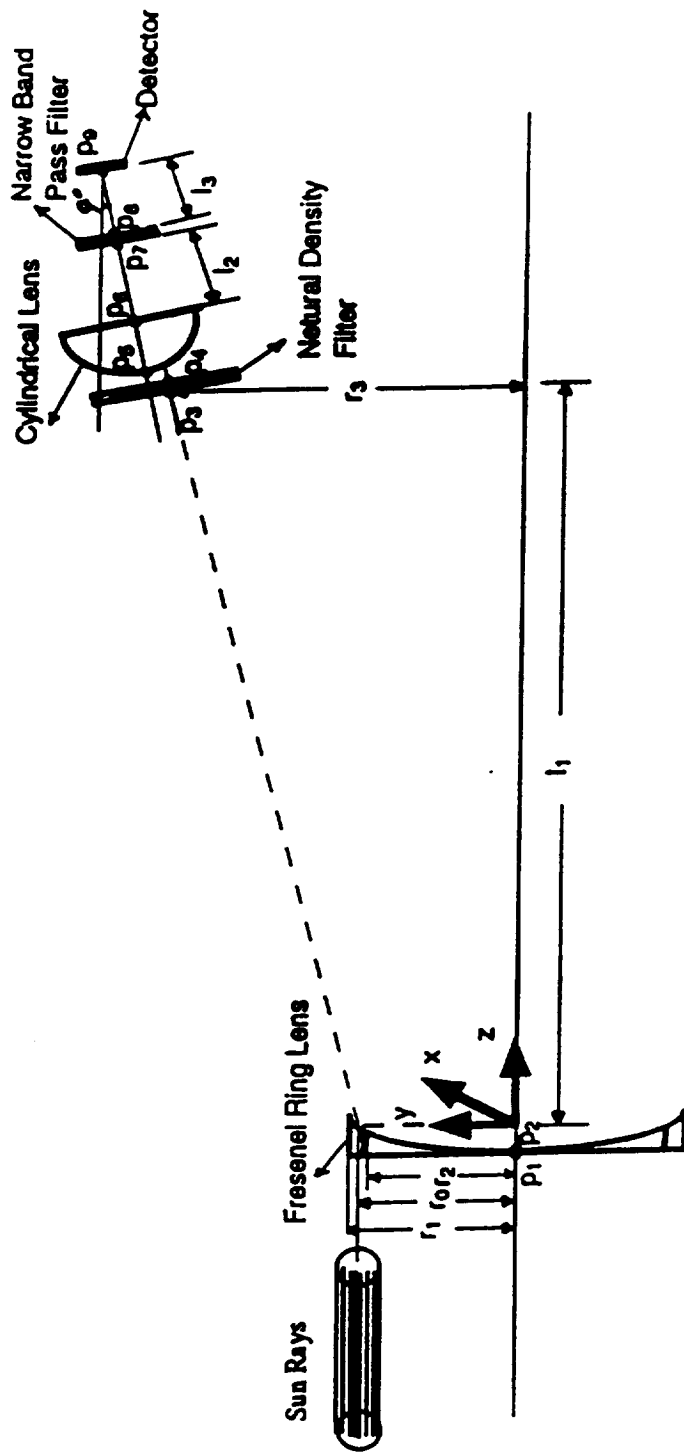
3.1 Introduction

This section documents the configuration and optical prescription of the optical system of the Shooting Star Experiment (SSE) provided by Mr. Gary W. Wilkerson, Micro Craft, Inc. in October 1997 and the performance analysis results of this optical system. This optical performance analysis was done using the Modeling and Analysis for Controller Optical Systems (MACOS) developed by JPL [1]. In order to determine the Sun pointing error, the SSE uses one Fresnel lens and four Sun image detecting optical assemblies that are located symmetrically on the spacecraft. Since the optical functions of four Sun image detecting optical systems are identical, only one Sun image detecting optical system that includes one Fresnel lens, two filters, one cylindrical lens, and one Charge Coupled Device (CCD) detector was modeled in this study. The ray tray analyses were performed to determine the Sun image movements on the CCD detector due to the rigid body motions of the SSE optical system and the motions of the Fresnel lens due to flexibility of inflatable supporting structure. These results may be easily translated to the other three Sun image detecting systems by adjusting coordinate systems.

3.2 SSE MACOS Optical Modeling and Analysis

In this section one Sun image detecting optical system that includes one Fresnel lens, two filters, one cylindrical lens, and one CCD detector was modeled via MACOS simulation. The hardware Fresnel ring lens that is made of multi-segments with various slopes was modeled mathematically as one aspheric surface lens whose curvature was derived by interpolating the various slopes of the multi-segments with center obscured. The difference of thickness between the hardware Fresnel lens and the MACOS model of Fresnel lens was corrected by moving back the vertex point of MACOS Fresnel lens by the thickness difference.

The pointing errors of the Fresnel lens to the center of Sun due to the rigid body motions of SSE optical system and the motions of Fresnel lens due to flexibility of inflatable supporting may be determined by measuring the movements of the center of the spot diagram on the CCD detector. This spot diagram was obtained for a bundle of collimated Sun rays from the ray tray analysis using MACOS. The nominal configuration of the SSE MACOS optical model and the coordinate system used for the ray tray analysis are shown in Figure 3.2-1.



Ring Lens:

$r_1=7.59$, $r_2=7.19$, $r_0=7.39$
 Thickness=0.003,
 Radius of Curvature=13.37423

Cylindrical Lens:

Thickness=1.41732, Radius of Curvature=4.80314
 Length=6.5, Width=2.5,
 Offset from center of N.D. filter=0.905510

Natural Density Filter:

$l_1=73.367853$, $r_3=19.010962$
 Diameter= 6, Thickness=0.25
 Gap to cylindrical lens=0.1

Narrow Band Pass Filter:

$l_2=2.999994$, $l_3=2.095673$
 Diameter=4, Thickness=0.2

Detector:

Thickness=0.1, Width=0.25, Length=1.18

$P_1=(0, 0, -1.37773)$, $P_2=(0, 0, -1.37473)$

$P_3=(0, 19.010962, 73.367853)$, $P_4=(0, 19.050071, 73.614775)$

$P_5=(0, 19.960076, 73.571891)$, $P_6=(0, 20.181793, 74.971761)$

$P_7=(0, 20.651086, 77.934820)$, $P_8=(0, 20.682383, 78.132358)$

$P_9=(0, 21.010218, 80.202230)$ (Note: length unit = inch)

Figure 3 2-1. Configuration of SSF MACOS Optical Model

The Sun has an apparent diameter of about 0.54 degrees with respect to the Line of Sight (LOS) of the SSE Fresnel lens. Assuming that the apparent diameter of the Sun may have little effect on the movement of the center of spot diagram of the Sun rays on the CCD detector through 0.4 inch width of ring lens, 1 inch square area of collimated Sun rays coming into the center of the ring lens aligned to the cylindrical lens and the CCD detector are used for the ray tray analyses. The indices of refraction of lens and filter are chosen based on the wave length of 720 *nano-miter* for the ray tray analyses.

The rigid body translational motions and rotational motion about the LOS axis (z-axis) of the SSE optical system barely contribute to the movement of the center of spot diagram on the CCD detector. However, the rigid body rotational motions about x and y axis change the movement of the center of spot diagram on the CCD detector. Therefore, the relationship between the rigid body rotational angle about x-axis and the movement of the center of spot diagram on the CCD detector is to be investigated in this study. The inflatable supporting structure of the SSE vehicle can cause relative motion of the Fresnel lens with respect to the rest of SSE optical system. The relative torsional motion about the SSE optical axis may not affect the movement of the center of spot diagram on the CCD detector. The relative z-axis motion is believed to be considerably small and its effect on the movement of the center of spot diagram on the CCD detector is not considered in this study. The relationships of the relative translational y-axis motion and rotational motion about x-axis with the movement of the center of spot diagram on the CCD detector are also to be investigated in this study.

The MACOS model of the SSE Sun image detecting optical system consists of nine optical elements according to the definition of MACOS software. Each lens or filter is defined using two *Refractor* type of elements. A Fresnel ring lens is defined using element #1 (Circular Flat Refractor) and element #2 (Circular Aspheric Refractor) with center obscured. A neutral density filter is defined using element #3 (Circular Flat Refractor) and element #4 (Circular Flat Refractor). The neutral density filter is tilted by 9 degrees with respect to optical axis of Fresnel lens as shown in Figure 3.2-1. A cylindrical lens that consists of a x-axis directional conic surface and a y-axis directional flat surface could be modeled using MACOS Anamorphic Refractor and Flat Refractor elements. However, since the MACOS Anamorphic Refractor element with 9 degrees tilt yields numerical instability problem, a cylindrical lens was defined using element #5 (Rectangular Conic Refractor) and element #6 (Rectangular Flat Refractor). This approximation may introduce spot diagram errors only in the x-axis direction and has insignificant effect on the movement (y-axis directional) of the center of spot diagram on the CCD detector. A narrow band pass filter is defined using element #7 (Circular Flat Refractor) and element #8 (Circular Flat Refractor). A CCD detector is defined using element #9 (Rectangular Flat FocalPlane). The central optical line of cylindrical lens, narrow band pass filter and CCD detector is offset by 0.905510 inch with respect to the central optical line of neutral density filter as shown in Figure 3.2-1.

The dimensions of the SSE MACOS optical elements are defined in Figure 3.2-1. Each vertex point of nine elements is denoted as $p_i, (i = 1, \dots, 9)$ and shown in Figure 3.2-1 with

respect to the global coordinate system. Since the focal distance, l_1 was determined by the SSE optics design team for the Fresnel lens of 0.003 inch thickness, the vertex points of elements #2 and #3 (p_1 and p_2) are moved back by the height of the aspheric surface at the center of the ring lens from the origin of the global coordinate that located at the center of the ring lens on the SSE optical axis. The prescriptions of the SSE MACOS optical elements are summarized in Table 3.2-1.

Table 3.2-1: Optical Prescriptions of SSE MACOS Optical Elements
(length unit = inch)

Optical Element No.	Element Type	Surface Type	Radius of Curvature / Aspheric Coeff.	Index of Refraction	Principal Axis Direction
1	Refractor	Flat	-1e22 / 0	1.595059	(0,0,-1)
2	Refractor	Aspheric	13.37423 / A=0.414552e-3, B=-0.344476e-5, C=0.199075e-7	1.	(0,0,-1)
3	Refractor	Flat	-1e22 / 0	1.454853	(0,-0.1564,-0.9877)
4	Refractor	Flat	-1e22 / 0	1.	(0,-0.1564,-0.9877)
5	Refractor	Conic	4.80314 / 0	1.512549	(0,-0.1564,-0.9877)
6	Refractor	Flat	-1e22 / 0	1.	(0,-0.1564,-0.9877)
7	Refractor	Flat	-1e22 / 0	1.454853	(0,-0.1564,-0.9877)
8	Refractor	Flat	-1e22 / 0	1.	(0,-0.1564,-0.9877)
9	FocalPlane	Flat	-1e22 / 0	1.	(0,-0.1564,-0.9877)

3.3 SSE Optics MACOS Simulation Results

A MACOS model of the SSE Sun image detecting system was first developed for the nominal configuration shown in Figure 3.2-1. The optical prescriptions and configuration of the SSE optical model provided by the SSE Optical Design Team were confirmed through the ray tray analysis using MACOS. The input file of the SSE MACOS simulation for the nominal configuration is attached in Appendix G. In order to determine the Sun image movement on the CCD detector due to the rigid body motion of the SSE optical system and the motion of the Fresnel lens that may result from the flexibility of inflatable supporting structure, the ray tray analyses were performed using MACOS for following three cases; case1: y-axis translational movement of Sun image on the CCD detector due to the rigid body rotational motion about the x-axis of total SSE optical system, case 2: y-axis translational movement of Sun image on the CCD detector due to the y-axis directional movement of the Fresnel lens only, case 3: y-axis translational movement of Sun image on the CCD detector due to rotation about the x-axis of the Fresnel lens only.

Case 1:

In order to determine the y-axis translational Sun image movement on the CDD detector due to the rigid body rotational motion of about the x-axis of total SSE optical system, all nine elements of the nominal SSE MACOS optical model were rotated about x-axis at node p_1 by various angles and the ray tray analyses were performed with a bundle of collimated rays fully covering the width of ring lens. The y-axis locations of chief ray and center of spot diagram of the collimated Sun rays at the ring lens and the CCD detector were calculated using MACOS for the various rotational angles of the SSE optical system and summarized in Table 3.3-1 with respect to the global coordinate system defined in Figure 3.2-1.

Table 3.3-1: SSE Rigid Body Rotation vs. Movement of Sun Image at Detector
(length unit = inch)

Rigid body rotation about x-axis (degree)	Chief ray location at ring lens (y-axis)	Center of spot diagram location at ring lens (y-axis)	Chief ray location at detector (y-axis)	Center of spot diagram location at detector (y-axis)
-0.5	7.39	7.3844	21.1542	21.1508
-0.4	7.39	7.3845	21.0628	21.0593
-0.2	7.39	7.3845	20.8841	20.8801
0.	7.39	7.3892	20.7089	20.7048
0.2	7.39	7.3845	20.5364	20.5322
0.4	7.39	7.3845	20.3655	20.3612
0.6	7.39	7.3843	20.1954	20.1910
0.8	7.39	7.3839	20.0255	20.0134
1.0	7.39	7.3836	19.8549	19.8507
1.2	7.39	7.3829	19.6828	19.6786
1.4	7.39	7.3822	19.5084	19.5045
1.5	7.39	7.3818	19.4197	19.4159

w.r.t. global coordinate system

The actual Sun image movement on the CDD detector due to the rigid body rotation about the x-axis of the SSE optical system is determined by subtracting the movement of the CCD detector center from the movement of the spot diagram center of the collimated Sun rays at the CCD detector and plotted in Figure 3.3-1. The movements of the CCD detector center and of the spot diagram center of the collimated Sun rays at the CCD detector are obtained by calculating relative displacements with respect to nominal

positions from Table 3.3-1. As shown in Figure 3.3-1, the 1.18 inch length of the CCD detector can allow rigid body rotation of the SSE vehicle about the x-axis from -0.5 degrees to 1.5 degrees. Since two Sun image detecting systems are located symmetrically about the center line of the SSE vehicle, total Field of View (FOV) allowed for the rigid body rotation of the SSE optical system about the x-axis is ± 1.5 degrees.

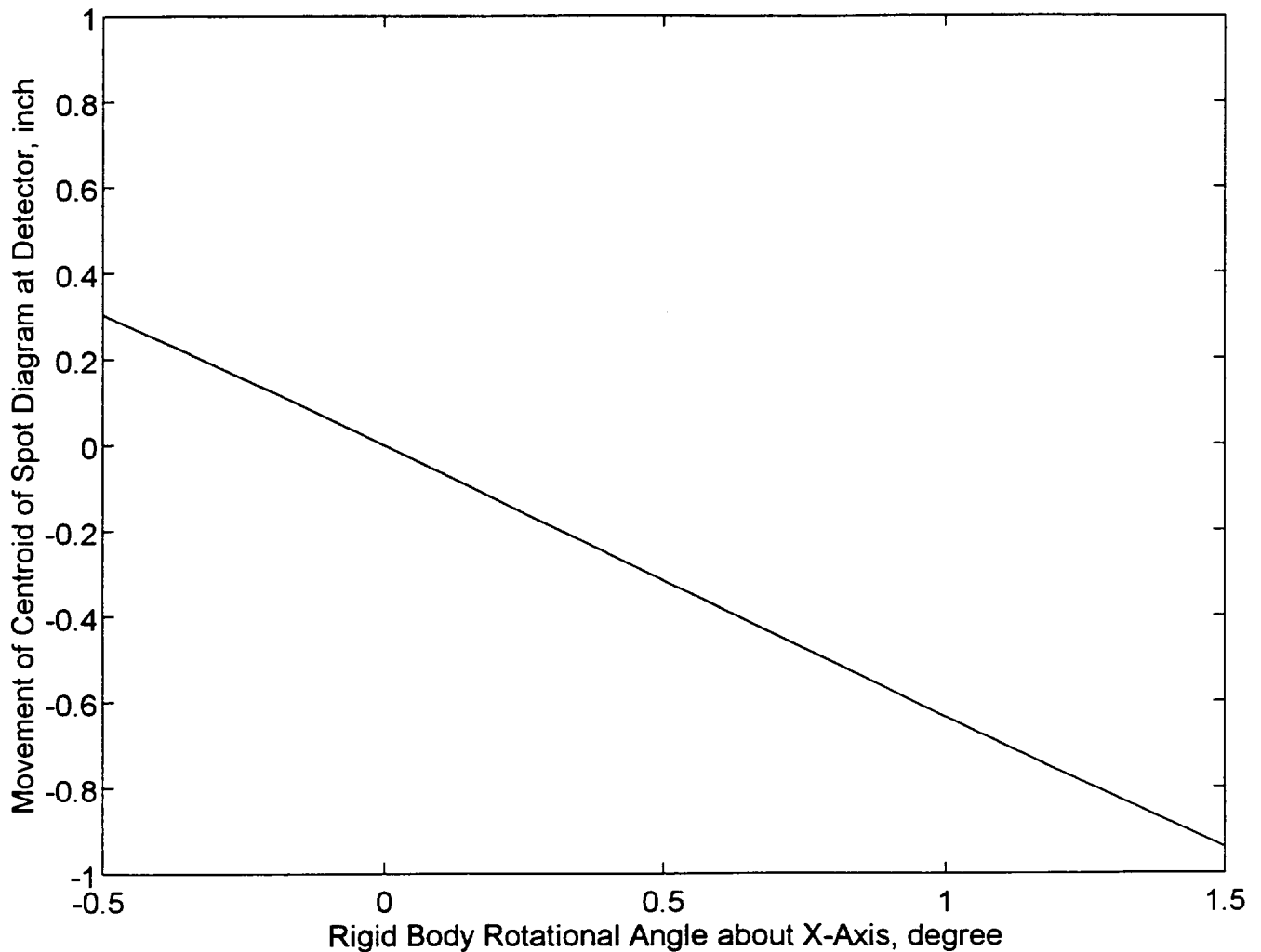


Figure 3.3-1: Movement of Centroid of Spot Diagram at Detector due to SSE Rigid Body Rotational Motion about X-Axis

Case 2:

In order to determine the y-axis translational movement of the Sun image on the CCD detector due to the y-axis translational movement of the Fresnel lens that may result from the flexibility of inflatable supporting structure, the incoming bundle of Sun rays and the Fresnel lens were moved by various distances in the y-axis direction and the ray tray analyses were performed. The y-axis locations of chief ray and center of spot diagram of the collimated Sun rays at the ring lens and the CCD detector were calculated using MACOS for the various movement of the Fresnel lens and are summarized in Table 3.3-2 with respect to the global coordinate system.

Table 3.3-2: Movement of Ring Lens vs. Movement of Sun Image at Detector
(length unit = inch)

Movement of ring lens (y-axis)	Chief ray location at ring lens (y-axis)	Center of spot diagram location at ring lens (y-axis)	Chief ray location at detector (y-axis)	Center of spot diagram location at detector (y-axis)
-0.9	6.49	6.4892	20.4400	20.4400
-0.8	6.59	6.5892	20.4675	20.4640
-0.6	6.79	6.7892	20.5246	20.5209
-0.4	6.99	6.9892	20.5841	20.5803
-0.2	7.19	7.1892	20.6457	20.6417
0.	7.39	7.3892	20.7089	20.7048
0.2	7.59	7.5892	20.7734	20.7692
0.4	7.79	7.7892	20.8388	20.8345
0.6	7.99	7.9892	20.9049	20.9005
0.8	8.19	8.1892	20.9714	20.9669
1.0	8.39	8.3892	21.0380	21.0335
1.2	8.59	8.5892	21.1046	21.1000
1.4	8.79	8.7892	21.1707	21.1663
1.6	8.99	8.9892	21.2362	21.2317
1.8	9.19	9.1892	21.3009	21.2963
2.0	9.39	9.3892	21.3644	21.3598
2.2	9.59	9.5892	21.4262	21.4217
2.4	9.79	9.7892	21.4862	21.4817
2.6	9.99	9.9892	21.5437	21.5393
2.8	10.19	10.1893	21.5983	21.5902

w.r.t. global coordinate system

The actual Sun image movement on the CDD detector due to the y-axis translational movement of the Fresnel lens is determined by calculating the relative displacements of the

spot diagram center of the collimated Sun rays at the CCD detector with respect to the nominal positions from Table 3.3-2 and plotted in Figure 3.3-2. It is shown that the 1.18 inch length of CCD detector can allow relative y-axis translational movement of the Fresnel lens with respect to the rest of optical system from -0.9 inch to 2.8 inch. Since two Sun image detecting systems are located symmetrically about the center line of the SSE vehicle, total relative y-axis translational movement of the Fresnel lens with respect to the rest elements of the optical system due to the flexibility of the inflatable supporting structure is ± 2.8 inch.

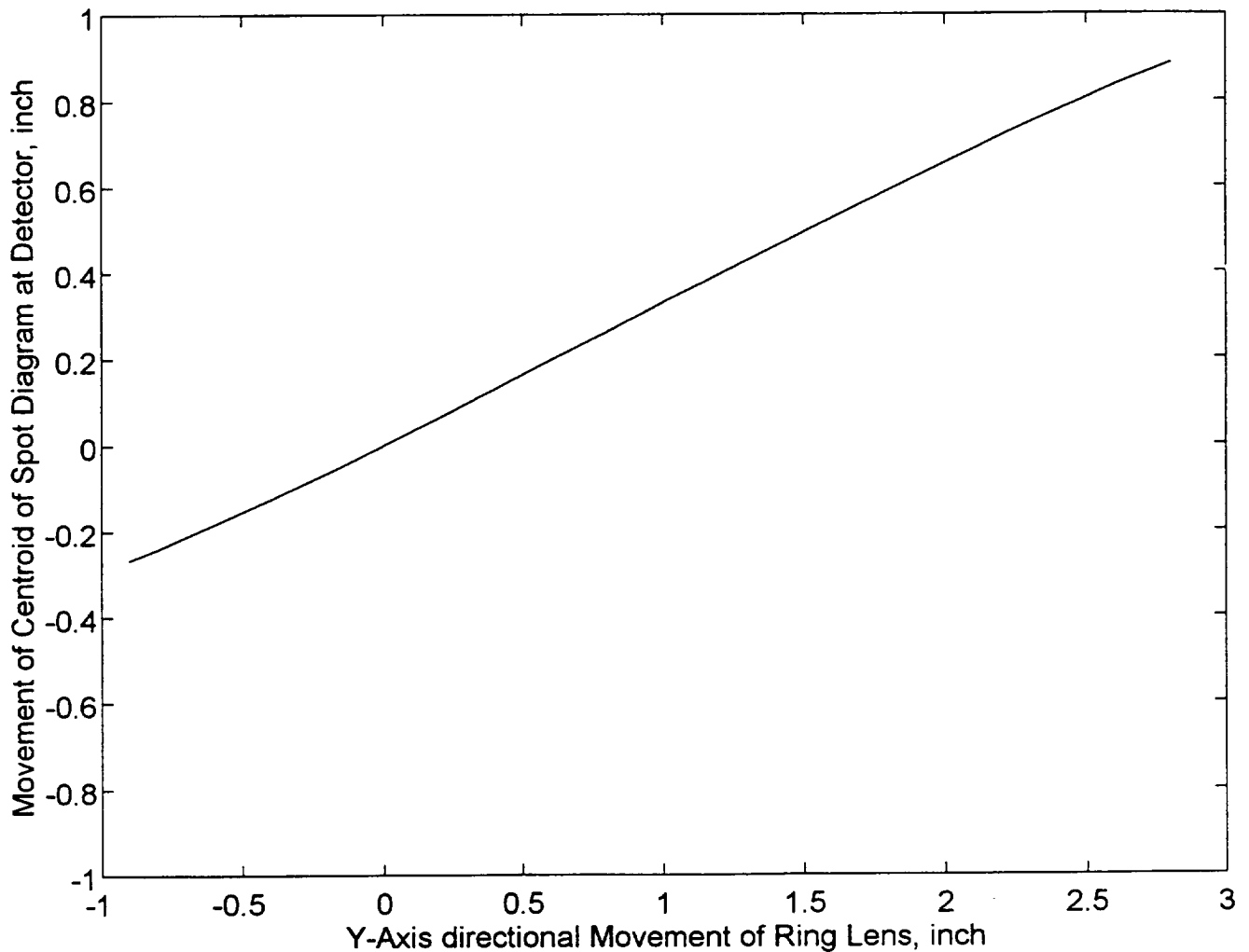


Figure 3.3-2: Movement of Centroid of Spot Diagram at Detector due to Y-Axis Directional Movement of Fresnel Ring Lens

Case 3:

In order to determine the y-axis translational movement of the Sun image on the CCD detector due to the rotation of the Fresnel lens about the x-axis that may result from the flexibility of the inflatable supporting structure, the Fresnel lens were rotated by various angles about the x-axis and the ray tray analyses were performed with a bundle of collimated rays fully covering the width of the ring lens. The y-axis locations of the chief ray and the center of the spot diagram of the collimated Sun rays at the ring lens and the CCD detector were calculated using MACOS for the various rotations of the Fresnel lens. The results are summarized in Table 3.3-3 with respect to the global coordinate system.

Table 3.3-3: Rotation of Ring Lens vs. Movement of Image at Detector
(length unit = inch)

Rotation of ring lens about x-axis (degree)	Chief ray location at ring lens (y-axis)	Center of spot diagram location at ring lens (y-axis)	Chief ray location at detector (y-axis)	Center of spot diagram location at detector (y-axis)
-6.0	7.39	7.3473	20.6521	20.6502
-5.5	7.39	7.3533	20.6542	20.6524
-5.0	7.39	7.3586	20.6569	20.6550
-4.5	7.39	7.3633	20.6600	20.6577
-4.0	7.39	7.3682	20.6636	20.6613
-3.5	7.39	7.3724	20.6676	20.6652
-3.0	7.39	7.3762	20.6721	20.6694
-2.5	7.39	7.3787	20.6771	20.6742
-2.0	7.39	7.3811	20.6825	20.6795
-1.5	7.39	7.3833	20.6884	20.6850
-1.0	7.39	7.3849	20.6948	20.6911
-0.5	7.39	7.3856	20.7016	20.6977
0.	7.39	7.3892	20.7089	20.7048
0.5	7.39	7.3856	20.7167	20.7127
1.0	7.39	7.3849	20.7249	20.7211
1.5	7.39	7.3833	20.7335	20.7301
2.0	7.39	7.3811	20.7426	20.7396
2.5	7.39	7.3787	20.7521	20.7495
3.0	7.39	7.3762	20.7621	20.7601
3.5	7.39	7.3724	20.7724	20.7712
4.0	7.39	7.3682	20.7832	20.7829
4.5	7.39	7.3633	20.7943	20.7951
5.0	7.39	7.3586	20.8058	20.8084
5.5	7.39	7.3533	20.8176	20.8217
6.0	7.39	7.3473	20.8298	20.8364

w.r.t. global coordinate system

The actual Sun image movements on the CDD detector due to the rotations of the Fresnel lens about the x-axis were determined by calculating relative displacements of the spot diagram center of the collimated Sun rays at the CCD detector with respect to the nominal positions from Table 3.3-3 and are plotted in Figure 3.3-3. It is shown that the relative rotation of the Fresnel lens about the x-axis with respect to the rest of the optical system due to the flexibility of the inflatable supporting structure is insignificant comparing to those of Case 1 and Case 2.

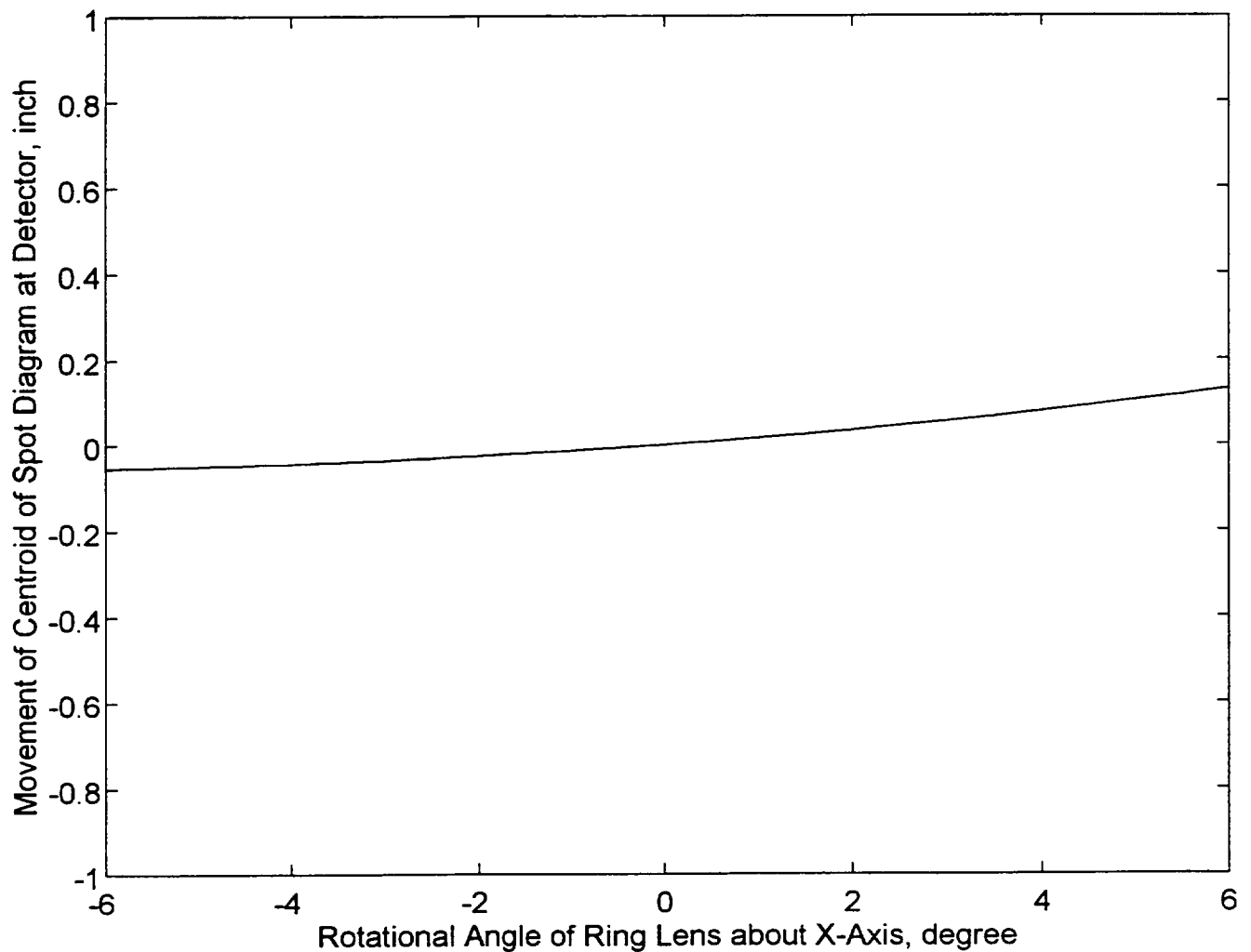


Figure 3.3-3: Movement of Centroid of Spot Diagram at Detector due to Rotational Motion of Fresnel Ring Lens about X-Axis

3.4 Conclusion

A mathematical optical model was developed for the up-to-date configuration and optical prescriptions of SSE Sun image detector system using MACOS software. In order to determine the Sun pointing error of the SSE optical system, the ray tray analyses were performed using the collimated Sun rays without the effects of apparent diameter of Sun and blur. Even though the 0.54 degrees of apparent diameter and blur of Sun may seem to have little effect on the movement of the center of spot diagram of the Sun rays on the CCD detector through 0.4 inch width of the ring lens, further study will be needed to confirm this assumption.

The rigid body rotations of the SSE vehicle about the x-axis and y-axis and the relative x-axis and y-axis translational movements of the Fresnel lens with respect to the rest elements of the SSE optical system result in dominant effects on the movement of the center of spot diagram of the Sun rays on the CCD detector. With the given 1.18 inch length of the CCD detector total field of view allowed for the rigid body rotation of the SSE system about the x-axis is ± 1.5 degrees and the allowable relative x-axis and y-axis translational movements of the Fresnel lens with respect to the rest elements of the SSE optical system are ± 2.8 inch without rigid body motion. The coupling effects of rigid body motion and flexible motion are not included in this study and further study is required to investigate these effects.

Since there are no distinctions between the movements of the center of spot diagram of the Sun rays on the CCD detector due to the rigid body rotations of the SSE vehicle about the x-axis and the relative y-axis translational movements of the Fresnel lens with respect to the rest of the SSE optical elements, these must be considered to design the attitude controller of the SSE vehicle.

3.5 References

- [1] "Modeling and Analysis for Controlled Optical Systems User Manual," Jet Propulsion Laboratory, January 25, 1996


```

C
C INITIALIZE PARAMETERS
C
      DO 2 I=1,3
2      CIP(I)=0.D0
C
C DEFINE PID CONTROL PARAMETERS
C
C SAMPLING TIME
C
      DTFC=0.064D0
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
C PROPORTIONAL GAIN
      KP(1)=cntdta(1)
      KP(2)=cntdta(2)
      KP(3)=cntdta(3)
C INTEGRAL GAIN
      KI(1)=cntdta(4)
      KI(2)=cntdta(5)
      KI(3)=cntdta(6)
C RATE GAIN
      KR(1)=cntdta(7)
      KR(2)=cntdta(8)
      KR(3)=cntdta(9)
C POSITION LIMITER, LP (rad)
      THELIM(1)=cntdta(10)
      THELIM(2)=cntdta(11)
      THELIM(3)=cntdta(12)
C INTEGRAL LIMITER, LI (rad-sec)
      CILIM(1)=cntdta(13)
      CILIM(2)=cntdta(14)
      CILIM(3)=cntdta(15)
C RATE LIMITER, LR (rad/sec)
c according to DM05 dated on 2/28/97
      OMELIM(1)=cntdta(16)
      OMELIM(2)=cntdta(17)
      OMELIM(3)=cntdta(18)
C BODY TORQUE COMMAND LIMITER (ft-lb)
      TPCLIM=cntdta(19)
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
C
C PSEUDO-INVERSE MATRIX FOR RW STEERING LAW
C
      D(1,1)=-0.333333D0
      D(1,2)=-0.333333D0
      D(1,3)=-0.192450D0
      D(2,1)=-0.333333D0
      D(2,2)= 0.D0
      D(2,3)=-0.384900D0
      D(3,1)=-0.333333D0
      D(3,2)= 0.333333D0
      D(3,3)=-0.192450D0
      D(4,1)=-0.333333D0
      D(4,2)= 0.333333D0
      D(4,3)= 0.192450D0
      D(5,1)=-0.333333D0
      D(5,2)= 0.D0
      D(5,3)= 0.384900D0
      D(6,1)=-0.333333D0
      D(6,2)=-0.333333D0
      D(6,3)= 0.192450D0
C
C BENDING FILTER (2ND ORDER DIGITAL FILTER)
C
      KBF(1,1)=7.94213D-5
      KBF(2,1)=1.588426D-4
      KBF(3,1)=7.94213D-5

```

```

      KBF(4,1)=-1.978409D0
      KBF(5,1)=0.978726D0
C
      KBF(1,2)=9.79132D-4
      KBF(2,2)=1.958264D-3
      KBF(3,2)=9.79132D-4
      KBF(4,2)=-1.910409D0
      KBF(5,2)=0.914326D0
C
      KBF(1,3)=9.79132D-4
      KBF(2,3)=1.958264D-3
      KBF(3,3)=9.79132D-4
      KBF(4,3)=-1.910409D0
      KBF(5,3)=0.914326D0
      ENDIF                      !end of initialization
C
C READ INTEGRATING AND RATE GYRO SENSORS OUTPUT
C
      DO 1 I=1,3
        THE(I)=U(I)
1      OME(I)=U(I+3)
C
C BEGIN CONTROL LAW CALCULATIONS
C
C LIMIT POSITION ERROR SIGNAL
C
      DO 100 I=1,3
100    THE(I)=DMAX1(-THELIM(I),DMIN1(THELIM(I),THE(I)))
C
C INTEGRAL AND PROPORTIONAL PATH SIGNALS
C
      DO 101 I=1,3
        OMP(I)=KP(I)*THE(I)
101    CI(I)=DTFC*THE(I)+CIP(I)
C
C LIMIT THE INTEGRAL PATH SIGNAL
C
      DO 57 I=1,3
57    CI(I)=DMAX1(-CILIM(I),DMIN1(CILIM(I),CI(I)))
      DO 102 I=1,3
        OMI(I)=KI(I)*CI(I)
102    CIP(I)=CI(I)
C
C LIMIT THE RATE COMMAND SIGNALS
C
      DO 56 I=1,3
56    OME(I)=DMAX1(-OMELIM(I),DMIN1(OMELIM(I),OME(I)))
      DO 103 I=1,3
        OMR(I)=KR(I)*OME(I)
C
C COMPUTE FEED FORWARD TORQUE FROM GG TORQUE AND MANEUVER TORQUE
C ** need to include the wXh term if you have a commanded rate
CYK    TFF3(I)=OMDMC(I)*IV(I,I)-TGG(I)-TQUNLD(I)
C
C TOTAL COMMANDED TORQUE SIGNAL PRIOR TO ADDING FEED FORWARD TORQUE
C
C 103 TPC(I)=OMR(I)+OMI(I)+OMP(I)
C NEW CONTROL LAW MOD MOVING INTEGRAL PATH
103    TPC(I)=OMR(I)+OMP(I)
CYK
      DO 565 I=1,3
565    TFF3(I)=0.D0
C
C COMMAND TORQUE BENDING FILTER
C
      CALL PCBF(T,KBF,TPC,TCF)
C

```

```

C PROPORTIONALLY LIMIT TOTAL TORQUE COMMAND
C
      DO 104 I=1,3
104  TCF(I)=DMAX1(-TPCLIM,DMIN1(TPCLIM,TCF(I)))
C
C ADD THE FEED FORWARD TORQUE
C
      DO 131 I=1,3
131  TCF(I)=TCF(I)+TFF3(I)
C
C TOTAL CONTROL TORQUE AT THE C.M. OF SPACECRAFT
C THIS INCLUDES MODIFICATION TO THE CONTROLLER THAT MOVES THE INTEGRAL PATH
C
      DO 59 I=1,3
        TC(I)= TCF(I)+OMI(I)
59  CONTINUE
C
C DISTRIBUTE TOTAL CONTROL TORQUE TO SIX REACTION USING RW STEERING LAW
C THE SIGN OF RW TORQUE IS OPPOSITE TO ONE OF CONTROL TORQUE OF S/C.
C
      CALL MDM(D,TC,TCRW,6,6,3,1)
C
      DO 595 I=1,6
        R(I)= TCRW(I)
595  CONTINUE
      RETURN
      END
C=====
      SUBROUTINE PCBF(T,KBF,TIN,TOUT)
      IMPLICIT DOUBLE PRECISION(A-H,O-Z)
C 2ND ORDER BENDING FILTER FOR PC COMMAND TORQUE
      DOUBLE PRECISION KBF(5,3),TIN(3),TOUT(3),S1(3),S2(3)
      IF(T.EQ.0.) THEN
        DO 1 I=1,3
          S1(I)=0.D0
1        S2(I)=0.D0
        ENDIF
        DO 2 I=1,3
          TOUT(I)=KBF(1,I)*TIN(I)+S1(I)
          S1(I)=KBF(2,I)*TIN(I)-KBF(4,I)*TOUT(I)+S2(I)
2        S2(I)=KBF(3,I)*TIN(I)-KBF(5,I)*TOUT(I)
        RETURN
      END

```

Appendix B **AXAF-I TREETOPS Input File AXAFI.INT**

TREETOPS REV 10 06/05/95

SIM CONTROL

1 SI	0 Title	AXAF-I(1/98)
2 SI	0 Simulation stop time	1000
3 SI	0 Plot data interval	0.064
4 SI	0 Integration type (R,S or U)	R
5 SI	0 Step size (sec)	0.0064
6 SI	0 Sandia integration absolute and relative error	
7 SI	0 Linearization option (L,Z or N)	L
8 SI	0 Restart option (Y/N)	N
9 SI	0 Contact force computation option (Y/N)	N
10 SI	0 Constraint force computation option (Y/N)	N
11 SI	0 Small angle speedup option (All,Bypass,First,Nth)	A
12 SI	0 Mass matrix speedup option (All,Bypass,First,Nth)	A
13 SI	0 Non-Linear speedup option (All,Bypass,First,Nth)	A
14 SI	0 Constraint speedup option (All,Bypass,First,Nth)	A
15 SI	0 Constraint stabilization option (Y/N)	N
16 SI	0 Stabilization epsilon	

BODY

17 BO	1 Body ID number	1
18 BO	1 Type (Rigid,Flexible,NASTRAN)	R
19 BO	1 Number of modes	
20 BO	1 Modal calculation option (0, 1 or 2)	
21 BO	1 Foreshortening option (Y/N)	
22 BO	1 Model reduction method (NO,MS,MC,CC,QM,CV)	
23 BO	1 NASTRAN data file FORTRAN unit number (40 - 60)	
24 BO	1 Number of augmented nodes (0 if none)	
25 BO	1 Damping matrix option (NS,CD,HL,SD)	
26 BO	1 Constant damping ratio	
27 BO	1 Low frequency, High frequency ratios	
28 BO	1 Mode ID number, damping ratio	
29 BO	1 Conversion factors: Length,Mass,Force	
30 BO	1 Inertia reference node (0=Bdy Ref Frm; 1=mass cen)	1
31 BO	1 Moments of inertia (kg-m2) Ixx,Iyy,Izz	4551,35830,35961
32 BO	1 Products of inertia (kg-m2) Ixy,Ixz,Iyz	94,-737,89
33 BO	1 Mass (kg)	310.57
34 BO	1 Number of Nodes	12
35 BO	1 Node ID, Node coord. (meters) x,y,z	1,31.32,-0.02,0.09
36 BO	1 Node ID, Node coord. (meters) x,y,z	2,0,0,0
37 BO	1 Node ID, Node coord. (meters) x,y,z	3,40.08,2.70,-2.70
38 BO	1 Node ID, Node coord. (meters) x,y,z	4,38.79,2.70,-2.70
39 BO	1 Node ID, Node coord. (meters) x,y,z	5,37.51,2.70,-2.70
40 BO	1 Node ID, Node coord. (meters) x,y,z	6,40.08,-2.70,-2.70
41 BO	1 Node ID, Node coord. (meters) x,y,z	7,38.79,-2.70,-2.70
42 BO	1 Node ID, Node coord. (meters) x,y,z	8,37.51,-2.70,-2.70
43 BO	1 Node ID, Node coord. (meters) x,y,z	9,37.65,4.94,0
44 BO	1 Node ID, Node coord. (meters) x,y,z	10,37.65,-4.94,0
45 BO	1 Node ID, Node coord. (meters) x,y,z	11,31,2.12,2.63
46 BO	1 Node ID, Node coord. (meters) x,y,z	12,31.28,3.28,1.98
47 BO	1 Node ID, Node structural joint ID	
48 BO	2 Body ID number	2
49 BO	2 Type (Rigid,Flexible,NASTRAN)	N
50 BO	2 Number of modes	6
51 BO	2 Modal calculation option (0, 1 or 2)	0
52 BO	2 Foreshortening option (Y/N)	N
53 BO	2 Model reduction method (NO,MS,MC,CC,QM,CV)	MS
54 BO	2 NASTRAN data file FORTRAN unit number (40 - 60)	41
55 BO	2 Number of augmented nodes (0 if none)	0

56 BO	2 Damping matrix option (NS,CD,HL,SD)	CD
57 BO	2 Constant damping ratio	0.
58 BO	2 Low frequency, High frequency ratios	
59 BO	2 Mode ID number, damping ratio	
60 BO	2 Conversion factors: Length,Mass,Force	0.08333,12,1
61 BO	2 Inertia reference node (0=Bdy Ref Frm; 1=mass cen)	0
62 BO	2 Moments of inertia (kg-m2) Ixx,Iyy,Izz	
63 BO	2 Products of inertia (kg-m2) Ixy,Ixz,Iyz	
64 BO	2 Mass (kg)	
65 BO	2 Number of Nodes	10
66 BO	2 Node ID, Node coord. (meters) x,y,z	
67 BO	2 Node ID, Node structural joint ID	2,72
68 BO	2 Node ID, Node structural joint ID	3,50
69 BO	2 Node ID, Node structural joint ID	4,54
70 BO	2 Node ID, Node structural joint ID	5,30
71 BO	2 Node ID, Node structural joint ID	6,34
72 BO	2 Node ID, Node structural joint ID	7,10
73 BO	2 Node ID, Node structural joint ID	8,14
74 BO	2 Node ID, Node structural joint ID	9,1
75 BO	2 Node ID, Node structural joint ID	10,4
76 BO	3 Body ID number	3
77 BO	3 Type (Rigid,Flexible,NASTRAN)	N
78 BO	3 Number of modes	6
79 BO	3 Modal calculation option (0, 1 or 2)	0
80 BO	3 Foreshortening option (Y/N)	N
81 BO	3 Model reduction method (NO,MS,MC,CC,QM,CV)	MS
82 BO	3 NASTRAN data file FORTRAN unit number (40 - 60)	42
83 BO	3 Number of augmented nodes (0 if none)	0
84 BO	3 Damping matrix option (NS,CD,HL,SD)	CD
85 BO	3 Constant damping ratio	0
86 BO	3 Low frequency, High frequency ratios	
87 BO	3 Mode ID number, damping ratio	
88 BO	3 Conversion factors: Length,Mass,Force	0.08333,12,1
89 BO	3 Inertia reference node (0=Bdy Ref Frm; 1=mass cen)	0
90 BO	3 Moments of inertia (kg-m2) Ixx,Iyy,Izz	
91 BO	3 Products of inertia (kg-m2) Ixy,Ixz,Iyz	
92 BO	3 Mass (kg)	
93 BO	3 Number of Nodes	10
94 BO	3 Node ID, Node coord. (meters) x,y,z	
95 BO	3 Node ID, Node structural joint ID	2,72
96 BO	3 Node ID, Node structural joint ID	3,50
97 BO	3 Node ID, Node structural joint ID	4,54
98 BO	3 Node ID, Node structural joint ID	5,30
99 BO	3 Node ID, Node structural joint ID	6,34
100 BO	3 Node ID, Node structural joint ID	7,10
101 BO	3 Node ID, Node structural joint ID	8,14
102 BO	3 Node ID, Node structural joint ID	9,1
103 BO	3 Node ID, Node structural joint ID	10,4
104 BO	11 Body ID number	11
105 BO	11 Type (Rigid,Flexible,NASTRAN)	R
106 BO	11 Number of modes	
107 BO	11 Modal calculation option (0, 1 or 2)	
108 BO	11 Foreshortening option (Y/N)	
109 BO	11 Model reduction method (NO,MS,MC,CC,QM,CV)	
110 BO	11 NASTRAN data file FORTRAN unit number (40 - 60)	
111 BO	11 Number of augmented nodes (0 if none)	
112 BO	11 Damping matrix option (NS,CD,HL,SD)	
113 BO	11 Constant damping ratio	
114 BO	11 Low frequency, High frequency ratios	
115 BO	11 Mode ID number, damping ratio	
116 BO	11 Conversion factors: Length,Mass,Force	
117 BO	11 Inertia reference node (0=Bdy Ref Frm; 1=mass cen)	1
118 BO	11 Moments of inertia (kg-m2) Ixx,Iyy,Izz	1.54E-2,1.54E-2,2.36E-2
119 BO	11 Products of inertia (kg-m2) Ixy,Ixz,Iyz	0,0,0
120 BO	11 Mass (kg)	0.23
121 BO	11 Number of Nodes	2
122 BO	11 Node ID, Node coord. (meters) x,y,z	1,0,0,0
123 BO	11 Node ID, Node coord. (meters) x,y,z	2,0,0,0
124 BO	11 Node ID, Node structural joint ID	
125 BO	12 Body ID number	12
126 BO	12 Type (Rigid,Flexible,NASTRAN)	R
127 BO	12 Number of modes	

128	BO	12	Modal calculation option (0, 1 or 2)	
129	BO	12	Foreshortening option (Y/N)	
130	BO	12	Model reduction method (NO,MS,MC,CC,QM,CV)	
131	BO	12	NASTRAN data file FORTRAN unit number (40 - 60)	
132	BO	12	Number of augmented nodes (0 if none)	
133	BO	12	Damping matrix option (NS,CD,HL,SD)	
134	BO	12	Constant damping ratio	
135	BO	12	Low frequency, High frequency ratios	
136	BO	12	Mode ID number, damping ratio	
137	BO	12	Conversion factors: Length,Mass,Force	
138	BO	12	Inertia reference node (0=Bdy Ref Frm; 1=mass cen)	1
139	BO	12	Moments of inertia (kg-m2) Ixx,Iyy,Izz	1.475E-2,1.475E-2,2.2125E-2
140	BO	12	Products of inertia (kg-m2) Ixy,Ixz,Iyz	0,0,0
141	BO	12	Mass (kg)	0.1823
142	BO	12	Number of Nodes	2
143	BO	12	Node ID, Node coord. (meters) x,y,z	1,0,0,0.1936
144	BO	12	Node ID, Node coord. (meters) x,y,z	2,0,0,0
145	BO	12	Node ID, Node structural joint ID	
146	BO	13	Body ID number	13
147	BO	13	Type (Rigid,Flexible,NASTRAN)	R
148	BO	13	Number of modes	
149	BO	13	Modal calculation option (0, 1 or 2)	
150	BO	13	Foreshortening option (Y/N)	
151	BO	13	Model reduction method (NO,MS,MC,CC,QM,CV)	
152	BO	13	NASTRAN data file FORTRAN unit number (40 - 60)	
153	BO	13	Number of augmented nodes (0 if none)	
154	BO	13	Damping matrix option (NS,CD,HL,SD)	
155	BO	13	Constant damping ratio	
156	BO	13	Low frequency, High frequency ratios	
157	BO	13	Mode ID number, damping ratio	
158	BO	13	Conversion factors: Length,Mass,Force	
159	BO	13	Inertia reference node (0=Bdy Ref Frm; 1=mass cen)	1
160	BO	13	Moments of inertia (kg-m2) Ixx,Iyy,Izz	0.03961,0.03961,0.07921
161	BO	13	Products of inertia (kg-m2) Ixy,Ixz,Iyz	0,0,-1E-6
162	BO	13	Mass (kg)	0.3659
163	BO	13	Number of Nodes	2
164	BO	13	Node ID, Node coord. (meters) x,y,z	1,0,-5E-6,0
165	BO	13	Node ID, Node coord. (meters) x,y,z	2,0,0,0
166	BO	13	Node ID, Node structural joint ID	
167	BO	21	Body ID number	21
168	BO	21	Type (Rigid,Flexible,NASTRAN)	R
169	BO	21	Number of modes	
170	BO	21	Modal calculation option (0, 1 or 2)	
171	BO	21	Foreshortening option (Y/N)	
172	BO	21	Model reduction method (NO,MS,MC,CC,QM,CV)	
173	BO	21	NASTRAN data file FORTRAN unit number (40 - 60)	
174	BO	21	Number of augmented nodes (0 if none)	
175	BO	21	Damping matrix option (NS,CD,HL,SD)	
176	BO	21	Constant damping ratio	
177	BO	21	Low frequency, High frequency ratios	
178	BO	21	Mode ID number, damping ratio	
179	BO	21	Conversion factors: Length,Mass,Force	
180	BO	21	Inertia reference node (0=Bdy Ref Frm; 1=mass cen)	1
181	BO	21	Moments of inertia (kg-m2) Ixx,Iyy,Izz	1.54E-2,1.54E-2,2.36E-2
182	BO	21	Products of inertia (kg-m2) Ixy,Ixz,Iyz	0,0,0
183	BO	21	Mass (kg)	0.23
184	BO	21	Number of Nodes	2
185	BO	21	Node ID, Node coord. (meters) x,y,z	1,0,0,0
186	BO	21	Node ID, Node coord. (meters) x,y,z	2,0,0,0
187	BO	21	Node ID, Node structural joint ID	
188	BO	22	Body ID number	22
189	BO	22	Type (Rigid,Flexible,NASTRAN)	R
190	BO	22	Number of modes	
191	BO	22	Modal calculation option (0, 1 or 2)	
192	BO	22	Foreshortening option (Y/N)	
193	BO	22	Model reduction method (NO,MS,MC,CC,QM,CV)	
194	BO	22	NASTRAN data file FORTRAN unit number (40 - 60)	
195	BO	22	Number of augmented nodes (0 if none)	
196	BO	22	Damping matrix option (NS,CD,HL,SD)	
197	BO	22	Constant damping ratio	
198	BO	22	Low frequency, High frequency ratios	
199	BO	22	Mode ID number, damping ratio	

200	BO	22	Conversion factors: Length,Mass,Force	
201	BO	22	Inertia reference node (0=Bdy Ref Frm; 1=mass cen)	1
202	BO	22	Moments of inertia (kg-m2) Ixx,Iyy,Izz	1.475E-2,1.475E-2,2.2125E-2
203	BO	22	Products of inertia (kg-m2) Ixy,Ixz,Iyz	0,0,0
204	BO	22	Mass (kg)	0.1823
205	BO	22	Number of Nodes	2
206	BO	22	Node ID, Node coord. (meters) x,y,z	1,0,0,0.1936
207	BO	22	Node ID, Node coord. (meters) x,y,z	2,0,0,0
208	BO	22	Node ID, Node structural joint ID	
209	BO	23	Body ID number	23
210	BO	23	Type (Rigid,Flexible,NASTRAN)	R
211	BO	23	Number of modes	
212	BO	23	Modal calculation option (0, 1 or 2)	
213	BO	23	Foreshortening option (Y/N)	
214	BO	23	Model reduction method (NO,MS,MC,CC,QM,CV)	
215	BO	23	NASTRAN data file FORTRAN unit number (40 - 60)	
216	BO	23	Number of augmented nodes (0 if none)	
217	BO	23	Damping matrix option (NS,CD,HL,SD)	
218	BO	23	Constant damping ratio	
219	BO	23	Low frequency, High frequency ratios	
220	BO	23	Mode ID number, damping ratio	
221	BO	23	Conversion factors: Length,Mass,Force	
222	BO	23	Inertia reference node (0=Bdy Ref Frm; 1=mass cen)	1
223	BO	23	Moments of inertia (kg-m2) Ixx,Iyy,Izz	0.03961,0.03961,0.07921
224	BO	23	Products of inertia (kg-m2) Ixy,Ixz,Iyz	0,0,-1E-6
225	BO	23	Mass (kg)	0.3659
226	BO	23	Number of Nodes	2
227	BO	23	Node ID, Node coord. (meters) x,y,z	1,0,-5E-6,0
228	BO	23	Node ID, Node coord. (meters) x,y,z	2,0,0,0
229	BO	23	Node ID, Node structural joint ID	
230	BO	31	Body ID number	31
231	BO	31	Type (Rigid,Flexible,NASTRAN)	R
232	BO	31	Number of modes	
233	BO	31	Modal calculation option (0, 1 or 2)	
234	BO	31	Foreshortening option (Y/N)	
235	BO	31	Model reduction method (NO,MS,MC,CC,QM,CV)	
236	BO	31	NASTRAN data file FORTRAN unit number (40 - 60)	
237	BO	31	Number of augmented nodes (0 if none)	
238	BO	31	Damping matrix option (NS,CD,HL,SD)	
239	BO	31	Constant damping ratio	
240	BO	31	Low frequency, High frequency ratios	
241	BO	31	Mode ID number, damping ratio	
242	BO	31	Conversion factors: Length,Mass,Force	
243	BO	31	Inertia reference node (0=Bdy Ref Frm; 1=mass cen)	1
244	BO	31	Moments of inertia (kg-m2) Ixx,Iyy,Izz	1.54E-2,1.54E-2,2.36E-2
245	BO	31	Products of inertia (kg-m2) Ixy,Ixz,Iyz	0,0,0
246	BO	31	Mass (kg)	0.23
247	BO	31	Number of Nodes	2
248	BO	31	Node ID, Node coord. (meters) x,y,z	1,0,0,0
249	BO	31	Node ID, Node coord. (meters) x,y,z	2,0,0,0
250	BO	31	Node ID, Node structural joint ID	
251	BO	32	Body ID number	32
252	BO	32	Type (Rigid,Flexible,NASTRAN)	R
253	BO	32	Number of modes	
254	BO	32	Modal calculation option (0, 1 or 2)	
255	BO	32	Foreshortening option (Y/N)	
256	BO	32	Model reduction method (NO,MS,MC,CC,QM,CV)	
257	BO	32	NASTRAN data file FORTRAN unit number (40 - 60)	
258	BO	32	Number of augmented nodes (0 if none)	
259	BO	32	Damping matrix option (NS,CD,HL,SD)	
260	BO	32	Constant damping ratio	
261	BO	32	Low frequency, High frequency ratios	
262	BO	32	Mode ID number, damping ratio	
263	BO	32	Conversion factors: Length,Mass,Force	
264	BO	32	Inertia reference node (0=Bdy Ref Frm; 1=mass cen)	1
265	BO	32	Moments of inertia (kg-m2) Ixx,Iyy,Izz	1.475E-2,1.475E-2,2.2125E-2
266	BO	32	Products of inertia (kg-m2) Ixy,Ixz,Iyz	0,0,0
267	BO	32	Mass (kg)	0.1823
268	BO	32	Number of Nodes	2
269	BO	32	Node ID, Node coord. (meters) x,y,z	1,0,0,0.1936
270	BO	32	Node ID, Node coord. (meters) x,y,z	2,0,0,0
271	BO	32	Node ID, Node structural joint ID	

272 BO	33	Body ID number	33
273 BO	33	Type (Rigid,Flexible,NASTRAN)	R
274 BO	33	Number of modes	
275 BO	33	Modal calculation option (0, 1 or 2)	
276 BO	33	Foreshortening option (Y/N)	
277 BO	33	Model reduction method (NO,MS,MC,CC,QM,CV)	
278 BO	33	NASTRAN data file FORTRAN unit number (40 - 60)	
279 BO	33	Number of augmented nodes (0 if none)	
280 BO	33	Damping matrix option (NS,CD,HL,SD)	
281 BO	33	Constant damping ratio	
282 BO	33	Low frequency, High frequency ratios	
283 BO	33	Mode ID number, damping ratio	
284 BO	33	Conversion factors: Length,Mass,Force	
285 BO	33	Inertia reference node (0=Bdy Ref Frm; 1=mass cen)	1
286 BO	33	Moments of inertia (kg-m2) Ixx,Iyy,Izz	0.03961,0.03961,0.07921
287 BO	33	Products of inertia (kg-m2) Ixy,Ixz,Iyz	0,0,-1E-6
288 BO	33	Mass (kg)	0.3659
289 BO	33	Number of Nodes	2
290 BO	33	Node ID, Node coord. (meters) x,y,z	1,0,-5E-6,0
291 BO	33	Node ID, Node coord. (meters) x,y,z	2,0,0,0
292 BO	33	Node ID, Node structural joint ID	
293 BO	41	Body ID number	41
294 BO	41	Type (Rigid,Flexible,NASTRAN)	R
295 BO	41	Number of modes	
296 BO	41	Modal calculation option (0, 1 or 2)	
297 BO	41	Foreshortening option (Y/N)	
298 BO	41	Model reduction method (NO,MS,MC,CC,QM,CV)	
299 BO	41	NASTRAN data file FORTRAN unit number (40 - 60)	
300 BO	41	Number of augmented nodes (0 if none)	
301 BO	41	Damping matrix option (NS,CD,HL,SD)	
302 BO	41	Constant damping ratio	
303 BO	41	Low frequency, High frequency ratios	
304 BO	41	Mode ID number, damping ratio	
305 BO	41	Conversion factors: Length,Mass,Force	
306 BO	41	Inertia reference node (0=Bdy Ref Frm; 1=mass cen)	1
307 BO	41	Moments of inertia (kg-m2) Ixx,Iyy,Izz	1.54E-2,1.54E-2,2.36E-2
308 BO	41	Products of inertia (kg-m2) Ixy,Ixz,Iyz	0,0,0
309 BO	41	Mass (kg)	0.23
310 BO	41	Number of Nodes	2
311 BO	41	Node ID, Node coord. (meters) x,y,z	1,0,0,0
312 BO	41	Node ID, Node coord. (meters) x,y,z	2,0,0,0
313 BO	41	Node ID, Node structural joint ID	
314 BO	42	Body ID number	42
315 BO	42	Type (Rigid,Flexible,NASTRAN)	R
316 BO	42	Number of modes	
317 BO	42	Modal calculation option (0, 1 or 2)	
318 BO	42	Foreshortening option (Y/N)	
319 BO	42	Model reduction method (NO,MS,MC,CC,QM,CV)	
320 BO	42	NASTRAN data file FORTRAN unit number (40 - 60)	
321 BO	42	Number of augmented nodes (0 if none)	
322 BO	42	Damping matrix option (NS,CD,HL,SD)	
323 BO	42	Constant damping ratio	
324 BO	42	Low frequency, High frequency ratios	
325 BO	42	Mode ID number, damping ratio	
326 BO	42	Conversion factors: Length,Mass,Force	
327 BO	42	Inertia reference node (0=Bdy Ref Frm; 1=mass cen)	1
328 BO	42	Moments of inertia (kg-m2) Ixx,Iyy,Izz	1.475E-2,1.475E-2,2.2125E-2
329 BO	42	Products of inertia (kg-m2) Ixy,Ixz,Iyz	0,0,0
330 BO	42	Mass (kg)	0.1823
331 BO	42	Number of Nodes	2
332 BO	42	Node ID, Node coord. (meters) x,y,z	1,0,0,0.1936
333 BO	42	Node ID, Node coord. (meters) x,y,z	2,0,0,0
334 BO	42	Node ID, Node structural joint ID	
335 BO	43	Body ID number	43
336 BO	43	Type (Rigid,Flexible,NASTRAN)	R
337 BO	43	Number of modes	
338 BO	43	Modal calculation option (0, 1 or 2)	
339 BO	43	Foreshortening option (Y/N)	
340 BO	43	Model reduction method (NO,MS,MC,CC,QM,CV)	
341 BO	43	NASTRAN data file FORTRAN unit number (40 - 60)	
342 BO	43	Number of augmented nodes (0 if none)	

343	BO	43	Damping matrix option (NS,CD,HL,SD)	
344	BO	43	Constant damping ratio	
345	BO	43	Low frequency, High frequency ratios	
346	BO	43	Mode ID number, damping ratio	
347	BO	43	Conversion factors: Length,Mass,Force	
348	BO	43	Inertia reference node (0=Bdy Ref Frm; 1=mass cen)	1
349	BO	43	Moments of inertia (kg-m2) Ixx,Iyy,Izz	0.03961,0.03961,0.07921
350	BO	43	Products of inertia (kg-m2) Ixy,Ixz,Iyz	0,0,-1E-6
351	BO	43	Mass (kg)	0.3659
352	BO	43	Number of Nodes	2
353	BO	43	Node ID, Node coord. (meters) x,y,z	1,0,-5E-6,0
354	BO	43	Node ID, Node coord. (meters) x,y,z	2,0,0,0
355	BO	43	Node ID, Node structural joint ID	
356	BO	51	Body ID number	51
357	BO	51	Type (Rigid,Flexible,NASTRAN)	R
358	BO	51	Number of modes	
359	BO	51	Modal calculation option (0, 1 or 2)	
360	BO	51	Foreshortening option (Y/N)	
361	BO	51	Model reduction method (NO,MS,MC,CC,QM,CV)	
362	BO	51	NASTRAN data file FORTRAN unit number (40 - 60)	
363	BO	51	Number of augmented nodes (0 if none)	
364	BO	51	Damping matrix option (NS,CD,HL,SD)	
365	BO	51	Constant damping ratio	
366	BO	51	Low frequency, High frequency ratios	
367	BO	51	Mode ID number, damping ratio	
368	BO	51	Conversion factors: Length,Mass,Force	
369	BO	51	Inertia reference node (0=Bdy Ref Frm; 1=mass cen)	1
370	BO	51	Moments of inertia (kg-m2) Ixx,Iyy,Izz	1.54E-2,1.54E-2,2.36E-2
371	BO	51	Products of inertia (kg-m2) Ixy,Ixz,Iyz	0,0,0
372	BO	51	Mass (kg)	0.23
373	BO	51	Number of Nodes	2
374	BO	51	Node ID, Node coord. (meters) x,y,z	1,0,0,0
375	BO	51	Node ID, Node coord. (meters) x,y,z	2,0,0,0
376	BO	51	Node ID, Node structural joint ID	
377	BO	52	Body ID number	52
378	BO	52	Type (Rigid,Flexible,NASTRAN)	R
379	BO	52	Number of modes	
380	BO	52	Modal calculation option (0, 1 or 2)	
381	BO	52	Foreshortening option (Y/N)	
382	BO	52	Model reduction method (NO,MS,MC,CC,QM,CV)	
383	BO	52	NASTRAN data file FORTRAN unit number (40 - 60)	
384	BO	52	Number of augmented nodes (0 if none)	
385	BO	52	Damping matrix option (NS,CD,HL,SD)	
386	BO	52	Constant damping ratio	
387	BO	52	Low frequency, High frequency ratios	
388	BO	52	Mode ID number, damping ratio	
389	BO	52	Conversion factors: Length,Mass,Force	
390	BO	52	Inertia reference node (0=Bdy Ref Frm; 1=mass cen)	1
391	BO	52	Moments of inertia (kg-m2) Ixx,Iyy,Izz	1.475E-2,1.475E-2,2.2125E-2
392	BO	52	Products of inertia (kg-m2) Ixy,Ixz,Iyz	0,0,0
393	BO	52	Mass (kg)	0.1823
394	BO	52	Number of Nodes	2
395	BO	52	Node ID, Node coord. (meters) x,y,z	1,0,0,0.1936
396	BO	52	Node ID, Node coord. (meters) x,y,z	2,0,0,0
397	BO	52	Node ID, Node structural joint ID	
398	BO	53	Body ID number	53
399	BO	53	Type (Rigid,Flexible,NASTRAN)	R
400	BO	53	Number of modes	
401	BO	53	Modal calculation option (0, 1 or 2)	
402	BO	53	Foreshortening option (Y/N)	
403	BO	53	Model reduction method (NO,MS,MC,CC,QM,CV)	
404	BO	53	NASTRAN data file FORTRAN unit number (40 - 60)	
405	BO	53	Number of augmented nodes (0 if none)	
406	BO	53	Damping matrix option (NS,CD,HL,SD)	
407	BO	53	Constant damping ratio	
408	BO	53	Low frequency, High frequency ratios	
409	BO	53	Mode ID number, damping ratio	
410	BO	53	Conversion factors: Length,Mass,Force	
411	BO	53	Inertia reference node (0=Bdy Ref Frm; 1=mass cen)	1
412	BO	53	Moments of inertia (kg-m2) Ixx,Iyy,Izz	0.03961,0.03961,0.07921
413	BO	53	Products of inertia (kg-m2) Ixy,Ixz,Iyz	0,0,-1E-6
414	BO	53	Mass (kg)	0.3659

415 BO	53	Number of Nodes	2
416 BO	53	Node ID, Node coord. (meters) x,y,z	1,0,-5E-6,0
417 BO	53	Node ID, Node coord. (meters) x,y,z	2,0,0,0
418 BO	53	Node ID, Node structural joint ID	
419 BO	61	Body ID number	61
420 BO	61	Type (Rigid,Flexible,NASTRAN)	R
421 BO	61	Number of modes	
422 BO	61	Modal calculation option (0, 1 or 2)	
423 BO	61	Foreshortening option (Y/N)	
424 BO	61	Model reduction method (NO,MS,MC,CC,QM,CV)	
425 BO	61	NASTRAN data file FORTRAN unit number (40 - 60)	
426 BO	61	Number of augmented nodes (0 if none)	
427 BO	61	Damping matrix option (NS,CD,HL,SD)	
428 BO	61	Constant damping ratio	
429 BO	61	Low frequency, High frequency ratios	
430 BO	61	Mode ID number, damping ratio	
431 BO	61	Conversion factors: Length,Mass,Force	
432 BO	61	Inertia reference node (0=Bdy Ref Frm; 1=mass cen)	1
433 BO	61	Moments of inertia (kg-m2) Ixx,Iyy,Izz	1.54E-2,1.54E-2,2.36E-2
434 BO	61	Products of inertia (kg-m2) Ixy,Ixz,Iyz	0,0,0
435 BO	61	Mass (kg)	0.23
436 BO	61	Number of Nodes	2
437 BO	61	Node ID, Node coord. (meters) x,y,z	1,0,0,0
438 BO	61	Node ID, Node coord. (meters) x,y,z	2,0,0,0
439 BO	61	Node ID, Node structural joint ID	
440 BO	62	Body ID number	62
441 BO	62	Type (Rigid,Flexible,NASTRAN)	R
442 BO	62	Number of modes	
443 BO	62	Modal calculation option (0, 1 or 2)	
444 BO	62	Foreshortening option (Y/N)	
445 BO	62	Model reduction method (NO,MS,MC,CC,QM,CV)	
446 BO	62	NASTRAN data file FORTRAN unit number (40 - 60)	
447 BO	62	Number of augmented nodes (0 if none)	
448 BO	62	Damping matrix option (NS,CD,HL,SD)	
449 BO	62	Constant damping ratio	
450 BO	62	Low frequency, High frequency ratios	
451 BO	62	Mode ID number, damping ratio	
452 BO	62	Conversion factors: Length,Mass,Force	
453 BO	62	Inertia reference node (0=Bdy Ref Frm; 1=mass cen)	1
454 BO	62	Moments of inertia (kg-m2) Ixx,Iyy,Izz	1.475E-2,1.475E-2,2.2125E-2
455 BO	62	Products of inertia (kg-m2) Ixy,Ixz,Iyz	0,0,0
456 BO	62	Mass (kg)	0.1823
457 BO	62	Number of Nodes	2
458 BO	62	Node ID, Node coord. (meters) x,y,z	1,0,0,0.1936
459 BO	62	Node ID, Node coord. (meters) x,y,z	2,0,0,0
460 BO	62	Node ID, Node structural joint ID	
461 BO	63	Body ID number	63
462 BO	63	Type (Rigid,Flexible,NASTRAN)	R
463 BO	63	Number of modes	
464 BO	63	Modal calculation option (0, 1 or 2)	
465 BO	63	Foreshortening option (Y/N)	
466 BO	63	Model reduction method (NO,MS,MC,CC,QM,CV)	
467 BO	63	NASTRAN data file FORTRAN unit number (40 - 60)	
468 BO	63	Number of augmented nodes (0 if none)	
469 BO	63	Damping matrix option (NS,CD,HL,SD)	
470 BO	63	Constant damping ratio	
471 BO	63	Low frequency, High frequency ratios	
472 BO	63	Mode ID number, damping ratio	
473 BO	63	Conversion factors: Length,Mass,Force	
474 BO	63	Inertia reference node (0=Bdy Ref Frm; 1=mass cen)	1
475 BO	63	Moments of inertia (kg-m2) Ixx,Iyy,Izz	0.03961,0.03961,0.07921
476 BO	63	Products of inertia (kg-m2) Ixy,Ixz,Iyz	0,0,-1E-6
477 BO	63	Mass (kg)	0.3659
478 BO	63	Number of Nodes	2
479 BO	63	Node ID, Node coord. (meters) x,y,z	1,0,-5E-6,0
480 BO	63	Node ID, Node coord. (meters) x,y,z	2,0,0,0
481 BO	63	Node ID, Node structural joint ID	

HINGE

482 HI	1	Hinge ID number	1
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483	HI	1	Inboard body ID, Outboard body ID	0,1
484	HI	1	"p" node ID, "q" node ID	0,1
485	HI	1	Number of rotation DOFs, Rotation option (F or G)	3,G
486	HI	1	L1 unit vector in inboard body coord. x,y,z	1,0,0
487	HI	1	L1 unit vector in outboard body coord. x,y,z	1,0,0
488	HI	1	L2 unit vector in inboard body coord. x,y,z	
489	HI	1	L2 unit vector in outboard body coord. x,y,z	
490	HI	1	L3 unit vector in inboard body coord. x,y,z	0,0,1
491	HI	1	L3 unit vector in outboard body coord. x,y,z	0,0,1
492	HI	1	Initial rotation angles (deg)	0,2.77778E-2,2.77778E-2
493	HI	1	Initial rotation rates (deg/sec)	0,8.E-4,8.E-4
494	HI	1	Rotation stiffness (newton-meters/rad)	0 0 0
495	HI	1	Rotation damping (newton-meters/rad/sec)	0 0 0
496	HI	1	Null torque angles (deg)	0 0 0
497	HI	1	Number of translation DOFs	0
498	HI	1	First translation unit vector g1	1 0 0
499	HI	1	Second translation unit vector g2	0 1 0
500	HI	1	Third translation unit vector g3	0 0 1
501	HI	1	Initial translation (meters)	0 0 0
502	HI	1	Initial translation velocity (meters/sec)	
503	HI	1	Translation stiffness (newtons/meters)	
504	HI	1	Translation damping (newtons/meter/sec)	
505	HI	1	Null force translations	
506	HI	2	Hinge ID number	2
507	HI	2	Inboard body ID, Outboard body ID	1,2
508	HI	2	"p" node ID, "q" node ID	9,2
509	HI	2	No of rotation DOFs, Hinge 1 rotation option(F/G)	0
510	HI	2	L1 unit vector in inboard body coord. x,y,z	0 1 0
511	HI	2	L1 unit vector in outboard body coord. x,y,z	0 1 0
512	HI	2	L2 unit vector in inboard body coord. x,y,z	
513	HI	2	L2 unit vector in outboard body coord. x,y,z	
514	HI	2	L3 unit vector in inboard body coord. x,y,z	1 0 0
515	HI	2	L3 unit vector in outboard body coord. x,y,z	1 0 0
516	HI	2	Initial rotation angles (deg)	0 0 0
517	HI	2	Initial rotation rates (deg/sec)	
518	HI	2	Rotation stiffness (newton-meters/rad)	
519	HI	2	Rotation damping (newton-meters/rad/sec)	
520	HI	2	Null torque angles (deg)	
521	HI	2	Number of translation DOFs	0
522	HI	2	First translation unit vector g1	1 0 0
523	HI	2	Second translation unit vector g2	0 1 0
524	HI	2	Third translation unit vector g3	0 0 1
525	HI	2	Initial translation (meters)	0 0 0
526	HI	2	Initial translation velocity (meters/sec)	
527	HI	2	Translation stiffness (newtons/meters)	
528	HI	2	Translation damping (newtons/meter/sec)	
529	HI	2	Null force translations	
530	HI	3	Hinge ID number	3
531	HI	3	Inboard body ID, Outboard body ID	1,3
532	HI	3	"p" node ID, "q" node ID	10,2
533	HI	3	Number of rotation DOFs, Rotation option (F or G)	0
534	HI	3	L1 unit vector in inboard body coord. x,y,z	0,-1,0
535	HI	3	L1 unit vector in outboard body coord. x,y,z	0,1,0
536	HI	3	L2 unit vector in inboard body coord. x,y,z	
537	HI	3	L2 unit vector in outboard body coord. x,y,z	
538	HI	3	L3 unit vector in inboard body coord. x,y,z	1,0,0
539	HI	3	L3 unit vector in outboard body coord. x,y,z	1,0,0
540	HI	3	Initial rotation angles (deg)	0 0 0
541	HI	3	Initial rotation rates (deg/sec)	
542	HI	3	Rotation stiffness (newton-meters/rad)	
543	HI	3	Rotation damping (newton-meters/rad/sec)	
544	HI	3	Null torque angles (deg)	
545	HI	3	Number of translation DOFs	0
546	HI	3	First translation unit vector g1	1 0 0
547	HI	3	Second translation unit vector g2	0 1 0
548	HI	3	Third translation unit vector g3	0 0 1
549	HI	3	Initial translation (meters)	0 0 0
550	HI	3	Initial translation velocity (meters/sec)	
551	HI	3	Translation stiffness (newtons/meters)	
552	HI	3	Translation damping (newtons/meter/sec)	
553	HI	3	Null force translations	
554	HI	11	Hinge ID number	11

555	HI	11	Inboard body ID, Outboard body ID	1,11
556	HI	11	"p" node ID, "q" node ID	3,1
557	HI	11	Number of rotation DOFs, Rotation option (F or G)	3
558	HI	11	L1 unit vector in inboard body coord. x,y,z	0.5,0.75,0.4330127
559	HI	11	L1 unit vector in outboard body coord. x,y,z	0,0,1
560	HI	11	L2 unit vector in inboard body coord. x,y,z	
561	HI	11	L2 unit vector in outboard body coord. x,y,z	
562	HI	11	L3 unit vector in inboard body coord. x,y,z	0.8660254,-0.4330127,-0.25
563	HI	11	L3 unit vector in outboard body coord. x,y,z	0,1,0
564	HI	11	Initial rotation angles (deg)	0 0 0
565	HI	11	Initial rotation rates (deg/sec)	0 0 0
566	HI	11	Rotation stiffness (newton-meters/rad)	204.7 204.7 204.7
567	HI	11	Rotation damping (newton-meters/rad/sec)	0.362 0.362 0.362
568	HI	11	Null torque angles (deg)	0 0 0
569	HI	11	Number of translation DOFs	3
570	HI	11	First translation unit vector g1	1 0 0
571	HI	11	Second translation unit vector g2	0 1 0
572	HI	11	Third translation unit vector g3	0 0 1
573	HI	11	Initial translation (meters)	0 0 0
574	HI	11	Initial translation velocity (meters/sec)	0 0 0
575	HI	11	Translation stiffness (newtons/meters)	2121.3 2121.3 2121.3
576	HI	11	Translation damping (newtons/meter/sec)	3.75 3.75 3.75
577	HI	11	Null force translations	0 0 0
578	HI	12	Hinge ID number	12
579	HI	12	Inboard body ID, Outboard body ID	11,12
580	HI	12	"p" node ID, "q" node ID	2,2
581	HI	12	Number of rotation DOFs	0
582	HI	12	L1 unit vector in inboard body coord. x,y,z	0,0,1
583	HI	12	L1 unit vector in outboard body coord. x,y,z	0,0,1
584	HI	12	L2 unit vector in inboard body coord. x,y,z	
585	HI	12	L2 unit vector in outboard body coord. x,y,z	
586	HI	12	L3 unit vector in inboard body coord. x,y,z	0,1,0
587	HI	12	L3 unit vector in outboard body coord. x,y,z	0,1,0
588	HI	12	Initial rotation angles (deg)	0 0 0
589	HI	12	Initial rotation rates (deg/sec)	
590	HI	12	Rotation stiffness (newton-meters/rad)	
591	HI	12	Rotation damping (newton-meters/rad/sec)	
592	HI	12	Null torque angles (deg)	
593	HI	12	Number of translation DOFs	0
594	HI	12	First translation unit vector g1	1 0 0
595	HI	12	Second translation unit vector g2	0 1 0
596	HI	12	Third translation unit vector g3	0 0 1
597	HI	12	Initial translation (meters)	0 0 0
598	HI	12	Initial translation velocity (meters/sec)	
599	HI	12	Translation stiffness (newtons/meters)	
600	HI	12	Translation damping (newtons/meter/sec)	
601	HI	12	Null force translations	
602	HI	13	Hinge ID number	13
603	HI	13	Inboard body ID, Outboard body ID	12,13
604	HI	13	"p" node ID, "q" node ID	1,1
605	HI	13	Number of rotation DOFs	1
606	HI	13	L1 unit vector in inboard body coord. x,y,z	0,0,1
607	HI	13	L1 unit vector in outboard body coord. x,y,z	0,0,1
608	HI	13	L2 unit vector in inboard body coord. x,y,z	
609	HI	13	L2 unit vector in outboard body coord. x,y,z	
610	HI	13	L3 unit vector in inboard body coord. x,y,z	0,1,0
611	HI	13	L3 unit vector in outboard body coord. x,y,z	0,1,0
612	HI	13	Initial rotation angles (deg)	0 0 0
613	HI	13	Initial rotation rates (deg/sec)	13500
614	HI	13	Rotation stiffness (newton-meters/rad)	0
615	HI	13	Rotation damping (newton-meters/rad/sec)	0
616	HI	13	Null torque angles (deg)	0
617	HI	13	Number of translation DOFs	0
618	HI	13	First translation unit vector g1	1 0 0
619	HI	13	Second translation unit vector g2	0 1 0
620	HI	13	Third translation unit vector g3	0 0 1
621	HI	13	Initial translation (meters)	0 0 0
622	HI	13	Initial translation velocity (meters/sec)	
623	HI	13	Translation stiffness (newtons/meters)	
624	HI	13	Translation damping (newtons/meter/sec)	
625	HI	13	Null force translations	
626	HI	21	Hinge ID number	21

627	HI	21	Inboard body ID, Outboard body ID	1,21
628	HI	21	"p" node ID, "q" node ID	4,1
629	HI	21	Number of rotation DOFs, Rotation option (F or G)	3
630	HI	21	L1 unit vector in inboard body coord. x,y,z	0.5,0,0.8660254
631	HI	21	L1 unit vector in outboard body coord. x,y,z	0,0,1
632	HI	21	L2 unit vector in inboard body coord. x,y,z	
633	HI	21	L2 unit vector in outboard body coord. x,y,z	
634	HI	21	L3 unit vector in inboard body coord. x,y,z	0.8660254,0,-0.5
635	HI	21	L3 unit vector in outboard body coord. x,y,z	0,1,0
636	HI	21	Initial rotation angles (deg)	0 0 0
637	HI	21	Initial rotation rates (deg/sec)	0 0 0
638	HI	21	Rotation stiffness (newton-meters/rad)	204.7 204.7 204.7
639	HI	21	Rotation damping (newton-meters/rad/sec)	0.362 0.362 0.362
640	HI	21	Null torque angles (deg)	0 0 0
641	HI	21	Number of translation DOFs	3
642	HI	21	First translation unit vector g1	1 0 0
643	HI	21	Second translation unit vector g2	0 1 0
644	HI	21	Third translation unit vector g3	0 0 1
645	HI	21	Initial translation (meters)	0 0 0
646	HI	21	Initial translation velocity (meters/sec)	0 0 0
647	HI	21	Translation stiffness (newtons/meters)	2121.3 2121.3 2121.3
648	HI	21	Translation damping (newtons/meter/sec)	3.75 3.75 3.75
649	HI	21	Null force translations	0 0 0
650	HI	22	Hinge ID number	22
651	HI	22	Inboard body ID, Outboard body ID	21,22
652	HI	22	"p" node ID, "q" node ID	2,2
653	HI	22	Number of rotation DOFs	0
654	HI	22	L1 unit vector in inboard body coord. x,y,z	0,0,1
655	HI	22	L1 unit vector in outboard body coord. x,y,z	0,0,1
656	HI	22	L2 unit vector in inboard body coord. x,y,z	
657	HI	22	L2 unit vector in outboard body coord. x,y,z	
658	HI	22	L3 unit vector in inboard body coord. x,y,z	0,1,0
659	HI	22	L3 unit vector in outboard body coord. x,y,z	0,1,0
660	HI	22	Initial rotation angles (deg)	0 0 0
661	HI	22	Initial rotation rates (deg/sec)	
662	HI	22	Rotation stiffness (newton-meters/rad)	
663	HI	22	Rotation damping (newton-meters/rad/sec)	
664	HI	22	Null torque angles (deg)	
665	HI	22	Number of translation DOFs	0
666	HI	22	First translation unit vector g1	1 0 0
667	HI	22	Second translation unit vector g2	0 1 0
668	HI	22	Third translation unit vector g3	0 0 1
669	HI	22	Initial translation (meters)	0 0 0
670	HI	22	Initial translation velocity (meters/sec)	
671	HI	22	Translation stiffness (newtons/meters)	
672	HI	22	Translation damping (newtons/meter/sec)	
673	HI	22	Null force translations	
674	HI	23	Hinge ID number	23
675	HI	23	Inboard body ID, Outboard body ID	22,23
676	HI	23	"p" node ID, "q" node ID	1,1
677	HI	23	Number of rotation DOFs	1
678	HI	23	L1 unit vector in inboard body coord. x,y,z	0,0,1
679	HI	23	L1 unit vector in outboard body coord. x,y,z	0,0,1
680	HI	23	L2 unit vector in inboard body coord. x,y,z	
681	HI	23	L2 unit vector in outboard body coord. x,y,z	
682	HI	23	L3 unit vector in inboard body coord. x,y,z	0,1,0
683	HI	23	L3 unit vector in outboard body coord. x,y,z	0,1,0
684	HI	23	Initial rotation angles (deg)	0 0 0
685	HI	23	Initial rotation rates (deg/sec)	-13500
686	HI	23	Rotation stiffness (newton-meters/rad)	0
687	HI	23	Rotation damping (newton-meters/rad/sec)	0
688	HI	23	Null torque angles (deg)	0
689	HI	23	Number of translation DOFs	0
690	HI	23	First translation unit vector g1	1 0 0
691	HI	23	Second translation unit vector g2	0 1 0
692	HI	23	Third translation unit vector g3	0 0 1
693	HI	23	Initial translation (meters)	0 0 0
694	HI	23	Initial translation velocity (meters/sec)	
695	HI	23	Translation stiffness (newtons/meters)	
696	HI	23	Translation damping (newtons/meter/sec)	
697	HI	23	Null force translations	
698	HI	31	Hinge ID number	31

699 HI	31	Inboard body ID, Outboard body ID	1,31
700 HI	31	"p" node ID, "q" node ID	5,1
701 HI	31	Number of rotation DOFs, Rotation option (F or G)	3
702 HI	31	L1 unit vector in inboard body coord. x,y,z	0.5,-0.75,0.4330127
703 HI	31	L1 unit vector in outboard body coord. x,y,z	0,0,1
704 HI	31	L2 unit vector in inboard body coord. x,y,z	
705 HI	31	L2 unit vector in outboard body coord. x,y,z	
706 HI	31	L3 unit vector in inboard body coord. x,y,z	0.8660254,0.4330127,-0.25
707 HI	31	L3 unit vector in outboard body coord. x,y,z	0,1,0
708 HI	31	Initial rotation angles (deg)	0 0 0
709 HI	31	Initial rotation rates (deg/sec)	0 0 0
710 HI	31	Rotation stiffness (newton-meters/rad)	204.7 204.7 204.7
711 HI	31	Rotation damping (newton-meters/rad/sec)	0.362 0.362 0.362
712 HI	31	Null torque angles (deg)	0 0 0
713 HI	31	Number of translation DOFs	3
714 HI	31	First translation unit vector g1	1 0 0
715 HI	31	Second translation unit vector g2	0 1 0
716 HI	31	Third translation unit vector g3	0 0 1
717 HI	31	Initial translation (meters)	0 0 0
718 HI	31	Initial translation velocity (meters/sec)	0 0 0
719 HI	31	Translation stiffness (newtons/meters)	2121.3 2121.3 2121.3
720 HI	31	Translation damping (newtons/meter/sec)	3.75 3.75 3.75
721 HI	31	Null force translations	0 0 0
722 HI	32	Hinge ID number	32
723 HI	32	Inboard body ID, Outboard body ID	31,32
724 HI	32	"p" node ID, "q" node ID	2,2
725 HI	32	Number of rotation DOFs	0
726 HI	32	L1 unit vector in inboard body coord. x,y,z	0,0,1
727 HI	32	L1 unit vector in outboard body coord. x,y,z	0,0,1
728 HI	32	L2 unit vector in inboard body coord. x,y,z	
729 HI	32	L2 unit vector in outboard body coord. x,y,z	
730 HI	32	L3 unit vector in inboard body coord. x,y,z	0,1,0
731 HI	32	L3 unit vector in outboard body coord. x,y,z	0,1,0
732 HI	32	Initial rotation angles (deg)	0 0 0
733 HI	32	Initial rotation rates (deg/sec)	
734 HI	32	Rotation stiffness (newton-meters/rad)	
735 HI	32	Rotation damping (newton-meters/rad/sec)	
736 HI	32	Null torque angles (deg)	
737 HI	32	Number of translation DOFs	0
738 HI	32	First translation unit vector g1	1 0 0
739 HI	32	Second translation unit vector g2	0 1 0
740 HI	32	Third translation unit vector g3	0 0 1
741 HI	32	Initial translation (meters)	0 0 0
742 HI	32	Initial translation velocity (meters/sec)	
743 HI	32	Translation stiffness (newtons/meters)	
744 HI	32	Translation damping (newtons/meter/sec)	
745 HI	32	Null force translations	
746 HI	33	Hinge ID number	33
747 HI	33	Inboard body ID, Outboard body ID	32,33
748 HI	33	"p" node ID, "q" node ID	1,1
749 HI	33	Number of rotation DOFs	1
750 HI	33	L1 unit vector in inboard body coord. x,y,z	0,0,1
751 HI	33	L1 unit vector in outboard body coord. x,y,z	0,0,1
752 HI	33	L2 unit vector in inboard body coord. x,y,z	
753 HI	33	L2 unit vector in outboard body coord. x,y,z	
754 HI	33	L3 unit vector in inboard body coord. x,y,z	0,1,0
755 HI	33	L3 unit vector in outboard body coord. x,y,z	0,1,0
756 HI	33	Initial rotation angles (deg)	0 0 0
757 HI	33	Initial rotation rates (deg/sec)	13500
758 HI	33	Rotation stiffness (newton-meters/rad)	0
759 HI	33	Rotation damping (newton-meters/rad/sec)	0
760 HI	33	Null torque angles (deg)	0
761 HI	33	Number of translation DOFs	0
762 HI	33	First translation unit vector g1	1 0 0
763 HI	33	Second translation unit vector g2	0 1 0
764 HI	33	Third translation unit vector g3	0 0 1
765 HI	33	Initial translation (meters)	0 0 0
766 HI	33	Initial translation velocity (meters/sec)	
767 HI	33	Translation stiffness (newtons/meters)	
768 HI	33	Translation damping (newtons/meter/sec)	
769 HI	33	Null force translations	
770 HI	41	Hinge ID number	41

771 HI	41 Inboard body ID, Outboard body ID	1,41
772 HI	41 "p" node ID, "q" node ID	6,1
773 HI	41 Number of rotation DOFs, Rotation option (F or G)	3
774 HI	41 L1 unit vector in inboard body coord. x,y,z	0.5,-0.75,-0.4330127
775 HI	41 L1 unit vector in outboard body coord. x,y,z	0,0,1
776 HI	41 L2 unit vector in inboard body coord. x,y,z	
777 HI	41 L2 unit vector in outboard body coord. x,y,z	
778 HI	41 L3 unit vector in inboard body coord. x,y,z	0.8660254,0.4330127,0.25
779 HI	41 L3 unit vector in outboard body coord. x,y,z	0,1,0
780 HI	41 Initial rotation angles (deg)	0 0 0
781 HI	41 Initial rotation rates (deg/sec)	0 0 0
782 HI	41 Rotation stiffness (newton-meters/rad)	204.7 204.7 204.7
783 HI	41 Rotation damping (newton-meters/rad/sec)	0.362 0.362 0.362
784 HI	41 Null torque angles (deg)	0 0 0
785 HI	41 Number of translation DOFs	3
786 HI	41 First translation unit vector g1	1 0 0
787 HI	41 Second translation unit vector g2	0 1 0
788 HI	41 Third translation unit vector g3	0 0 1
789 HI	41 Initial translation (meters)	0 0 0
790 HI	41 Initial translation velocity (meters/sec)	0 0 0
791 HI	41 Translation stiffness (newtons/meters)	2121.3 2121.3 2121.3
792 HI	41 Translation damping (newtons/meter/sec)	3.75 3.75 3.75
793 HI	41 Null force translations	0 0 0
794 HI	42 Hinge ID number	42
795 HI	42 Inboard body ID, Outboard body ID	41,42
796 HI	42 "p" node ID, "q" node ID	2,2
797 HI	42 Number of rotation DOFs	0
798 HI	42 L1 unit vector in inboard body coord. x,y,z	0,0,1
799 HI	42 L1 unit vector in outboard body coord. x,y,z	0,0,1
800 HI	42 L2 unit vector in inboard body coord. x,y,z	
801 HI	42 L2 unit vector in outboard body coord. x,y,z	
802 HI	42 L3 unit vector in inboard body coord. x,y,z	0,1,0
803 HI	42 L3 unit vector in outboard body coord. x,y,z	0,1,0
804 HI	42 Initial rotation angles (deg)	0 0 0
805 HI	42 Initial rotation rates (deg/sec)	
806 HI	42 Rotation stiffness (newton-meters/rad)	
807 HI	42 Rotation damping (newton-meters/rad/sec)	
808 HI	42 Null torque angles (deg)	
809 HI	42 Number of translation DOFs	0
810 HI	42 First translation unit vector g1	1 0 0
811 HI	42 Second translation unit vector g2	0 1 0
812 HI	42 Third translation unit vector g3	0 0 1
813 HI	42 Initial translation (meters)	0 0 0
814 HI	42 Initial translation velocity (meters/sec)	
815 HI	42 Translation stiffness (newtons/meters)	
816 HI	42 Translation damping (newtons/meter/sec)	
817 HI	42 Null force translations	
818 HI	43 Hinge ID number	43
819 HI	43 Inboard body ID, Outboard body ID	42,43
820 HI	43 "p" node ID, "q" node ID	1,1
821 HI	43 Number of rotation DOFs	1
822 HI	43 L1 unit vector in inboard body coord. x,y,z	0,0,1
823 HI	43 L1 unit vector in outboard body coord. x,y,z	0,0,1
824 HI	43 L2 unit vector in inboard body coord. x,y,z	
825 HI	43 L2 unit vector in outboard body coord. x,y,z	
826 HI	43 L3 unit vector in inboard body coord. x,y,z	0,1,0
827 HI	43 L3 unit vector in outboard body coord. x,y,z	0,1,0
828 HI	43 Initial rotation angles (deg)	0 0 0
829 HI	43 Initial rotation rates (deg/sec)	-13500
830 HI	43 Rotation stiffness (newton-meters/rad)	0
831 HI	43 Rotation damping (newton-meters/rad/sec)	0
832 HI	43 Null torque angles (deg)	0
833 HI	43 Number of translation DOFs	0
834 HI	43 First translation unit vector g1	1 0 0
835 HI	43 Second translation unit vector g2	0 1 0
836 HI	43 Third translation unit vector g3	0 0 1
837 HI	43 Initial translation (meters)	0 0 0
838 HI	43 Initial translation velocity (meters/sec)	
839 HI	43 Translation stiffness (newtons/meters)	
840 HI	43 Translation damping (newtons/meter/sec)	
841 HI	43 Null force translations	
842 HI	51 Hinge ID number	51

843	HI	51	Inboard body ID, Outboard body ID	1,51
844	HI	51	"p" node ID, "q" node ID	7,1
845	HI	51	Number of rotation DOFs, Rotation option (F or G)	3
846	HI	51	L1 unit vector in inboard body coord. x,y,z	0.5,0,-0.8660254
847	HI	51	L1 unit vector in outboard body coord. x,y,z	0,0,1
848	HI	51	L2 unit vector in inboard body coord. x,y,z	
849	HI	51	L2 unit vector in outboard body coord. x,y,z	
850	HI	51	L3 unit vector in inboard body coord. x,y,z	0.8660254,0,0.5
851	HI	51	L3 unit vector in outboard body coord. x,y,z	0,1,0
852	HI	51	Initial rotation angles (deg)	0 0 0
853	HI	51	Initial rotation rates (deg/sec)	0 0 0
854	HI	51	Rotation stiffness (newton-meters/rad)	204.7 204.7 204.7
855	HI	51	Rotation damping (newton-meters/rad/sec)	0.362 0.362 0.362
856	HI	51	Null torque angles (deg)	0 0 0
857	HI	51	Number of translation DOFs	3
858	HI	51	First translation unit vector g1	1 0 0
859	HI	51	Second translation unit vector g2	0 1 0
860	HI	51	Third translation unit vector g3	0 0 1
861	HI	51	Initial translation (meters)	0 0 0
862	HI	51	Initial translation velocity (meters/sec)	0 0 0
863	HI	51	Translation stiffness (newtons/meters)	2121.3 2121.3 2121.3
864	HI	51	Translation damping (newtons/meter/sec)	3.75 3.75 3.75
865	HI	51	Null force translations	0 0 0
866	HI	52	Hinge ID number	52
867	HI	52	Inboard body ID, Outboard body ID	51,52
868	HI	52	"p" node ID, "q" node ID	2,2
869	HI	52	Number of rotation DOFs	0
870	HI	52	L1 unit vector in inboard body coord. x,y,z	0,0,1
871	HI	52	L1 unit vector in outboard body coord. x,y,z	0,0,1
872	HI	52	L2 unit vector in inboard body coord. x,y,z	
873	HI	52	L2 unit vector in outboard body coord. x,y,z	
874	HI	52	L3 unit vector in inboard body coord. x,y,z	0,1,0
875	HI	52	L3 unit vector in outboard body coord. x,y,z	0,1,0
876	HI	52	Initial rotation angles (deg)	0 0 0
877	HI	52	Initial rotation rates (deg/sec)	
878	HI	52	Rotation stiffness (newton-meters/rad)	
879	HI	52	Rotation damping (newton-meters/rad/sec)	
880	HI	52	Null torque angles (deg)	
881	HI	52	Number of translation DOFs	0
882	HI	52	First translation unit vector g1	1 0 0
883	HI	52	Second translation unit vector g2	0 1 0
884	HI	52	Third translation unit vector g3	0 0 1
885	HI	52	Initial translation (meters)	0 0 0
886	HI	52	Initial translation velocity (meters/sec)	
887	HI	52	Translation stiffness (newtons/meters)	
888	HI	52	Translation damping (newtons/meter/sec)	
889	HI	52	Null force translations	
890	HI	53	Hinge ID number	53
891	HI	53	Inboard body ID, Outboard body ID	52,53
892	HI	53	"p" node ID, "q" node ID	1,1
893	HI	53	Number of rotation DOFs	1
894	HI	53	L1 unit vector in inboard body coord. x,y,z	0,0,1
895	HI	53	L1 unit vector in outboard body coord. x,y,z	0,0,1
896	HI	53	L2 unit vector in inboard body coord. x,y,z	
897	HI	53	L2 unit vector in outboard body coord. x,y,z	
898	HI	53	L3 unit vector in inboard body coord. x,y,z	0,1,0
899	HI	53	L3 unit vector in outboard body coord. x,y,z	0,1,0
900	HI	53	Initial rotation angles (deg)	0 0 0
901	HI	53	Initial rotation rates (deg/sec)	13500
902	HI	53	Rotation stiffness (newton-meters/rad)	0
903	HI	53	Rotation damping (newton-meters/rad/sec)	0
904	HI	53	Null torque angles (deg)	0
905	HI	53	Number of translation DOFs	0
906	HI	53	First translation unit vector g1	1 0 0
907	HI	53	Second translation unit vector g2	0 1 0
908	HI	53	Third translation unit vector g3	0 0 1
909	HI	53	Initial translation (meters)	0 0 0
910	HI	53	Initial translation velocity (meters/sec)	
911	HI	53	Translation stiffness (newtons/meters)	
912	HI	53	Translation damping (newtons/meter/sec)	
913	HI	53	Null force translations	
914	HI	61	Hinge ID number	61

915 HI	61 Inboard body ID, Outboard body ID	1,61
916 HI	61 "p" node ID, "q" node ID	8,1
917 HI	61 Number of rotation DOFs, Rotation option (F or G)	3
918 HI	61 L1 unit vector in inboard body coord. x,y,z	0.5,0.75,-0.4330127
919 HI	61 L1 unit vector in outboard body coord. x,y,z	0,0,1
920 HI	61 L2 unit vector in inboard body coord. x,y,z	
921 HI	61 L2 unit vector in outboard body coord. x,y,z	
922 HI	61 L3 unit vector in inboard body coord. x,y,z	0.8660254,-0.4330127,0.25
923 HI	61 L3 unit vector in outboard body coord. x,y,z	0,1,0
924 HI	61 Initial rotation angles (deg)	0 0 0
925 HI	61 Initial rotation rates (deg/sec)	0 0 0
926 HI	61 Rotation stiffness (newton-meters/rad)	204.7 204.7 204.7
927 HI	61 Rotation damping (newton-meters/rad/sec)	0.362 0.362 0.362
928 HI	61 Null torque angles (deg)	0 0 0
929 HI	61 Number of translation DOFs	3
930 HI	61 First translation unit vector g1	1 0 0
931 HI	61 Second translation unit vector g2	0 1 0
932 HI	61 Third translation unit vector g3	0 0 1
933 HI	61 Initial translation (meters)	0 0 0
934 HI	61 Initial translation velocity (meters/sec)	0 0 0
935 HI	61 Translation stiffness (newtons/meters)	2121.3 2121.3 2121.3
936 HI	61 Translation damping (newtons/meter/sec)	3.75 3.75 3.75
937 HI	61 Null force translations	0 0 0
938 HI	62 Hinge ID number	62
939 HI	62 Inboard body ID, Outboard body ID	61,62
940 HI	62 "p" node ID, "q" node ID	2,2
941 HI	62 Number of rotation DOFs	0
942 HI	62 L1 unit vector in inboard body coord. x,y,z	0,0,1
943 HI	62 L1 unit vector in outboard body coord. x,y,z	0,0,1
944 HI	62 L2 unit vector in inboard body coord. x,y,z	
945 HI	62 L2 unit vector in outboard body coord. x,y,z	
946 HI	62 L3 unit vector in inboard body coord. x,y,z	0,1,0
947 HI	62 L3 unit vector in outboard body coord. x,y,z	0,1,0
948 HI	62 Initial rotation angles (deg)	0 0 0
949 HI	62 Initial rotation rates (deg/sec)	
950 HI	62 Rotation stiffness (newton-meters/rad)	
951 HI	62 Rotation damping (newton-meters/rad/sec)	
952 HI	62 Null torque angles (deg)	
953 HI	62 Number of translation DOFs	0
954 HI	62 First translation unit vector g1	1 0 0
955 HI	62 Second translation unit vector g2	0 1 0
956 HI	62 Third translation unit vector g3	0 0 1
957 HI	62 Initial translation (meters)	0 0 0
958 HI	62 Initial translation velocity (meters/sec)	
959 HI	62 Translation stiffness (newtons/meters)	
960 HI	62 Translation damping (newtons/meter/sec)	
961 HI	62 Null force translations	
962 HI	63 Hinge ID number	63
963 HI	63 Inboard body ID, Outboard body ID	62,63
964 HI	63 "p" node ID, "q" node ID	1,1
965 HI	63 Number of rotation DOFs	1
966 HI	63 L1 unit vector in inboard body coord. x,y,z	0,0,1
967 HI	63 L1 unit vector in outboard body coord. x,y,z	0,0,1
968 HI	63 L2 unit vector in inboard body coord. x,y,z	
969 HI	63 L2 unit vector in outboard body coord. x,y,z	
970 HI	63 L3 unit vector in inboard body coord. x,y,z	0,1,0
971 HI	63 L3 unit vector in outboard body coord. x,y,z	0,1,0
972 HI	63 Initial rotation angles (deg)	0 0 0
973 HI	63 Initial rotation rates (deg/sec)	-13500
974 HI	63 Rotation stiffness (newton-meters/rad)	0
975 HI	63 Rotation damping (newton-meters/rad/sec)	0
976 HI	63 Null torque angles (deg)	0
977 HI	63 Number of translation DOFs	0
978 HI	63 First translation unit vector g1	1 0 0
979 HI	63 Second translation unit vector g2	0 1 0
980 HI	63 Third translation unit vector g3	0 0 1
981 HI	63 Initial translation (meters)	0 0 0
982 HI	63 Initial translation velocity (meters/sec)	
983 HI	63 Translation stiffness (newtons/meters)	
984 HI	63 Translation damping (newtons/meter/sec)	
985 HI	63 Null force translations	

SENSOR

986 SE	11	Sensor ID number	11
987 SE	11	Type (G,R,AN,V,P,AC,T,I,SU,ST,IM,P3,V3,CR,CT)	I
988 SE	11	Mounting point body ID, Mounting point node ID	1,1
989 SE	11	Second mounting point body ID, Second node ID	
990 SE	11	Input axis unit vector (IA) x,y,z	1,0,0
991 SE	11	Mounting point Hinge index, Axis index	
992 SE	11	First focal plane unit vector (Fp1) x,y,z	
993 SE	11	Second focal plane unit vector (Fp2) x,y,z	
994 SE	11	Sun/Star unit vector (Us) x,y,z	
995 SE	11	Euler Angle Sequence (1-6)	
996 SE	11	CMG ID number and Gimbal number	
997 SE	12	Sensor ID number	12
998 SE	12	Type (G,R,AN,V,P,AC,T,I,SU,ST,IM,P3,V3,CR,CT)	I
999 SE	12	Mounting point body ID, Mounting point node ID	1,1
1000 SE	12	Second mounting point body ID, Second node ID	
1001 SE	12	Input axis unit vector (IA) x,y,z	0,1,0
1002 SE	12	Mounting point Hinge index, Axis index	
1003 SE	12	First focal plane unit vector (Fp1) x,y,z	
1004 SE	12	Second focal plane unit vector (Fp2) x,y,z	
1005 SE	12	Sun/Star unit vector (Us) x,y,z	
1006 SE	12	Euler Angle Sequence (1-6)	
1007 SE	12	CMG ID number and Gimbal number	
1008 SE	13	Sensor ID number	13
1009 SE	13	Type (G,R,AN,V,P,AC,T,I,SU,ST,IM,P3,V3,CR,CT)	I
1010 SE	13	Mounting point body ID, Mounting point node ID	1,1
1011 SE	13	Second mounting point body ID, Second node ID	
1012 SE	13	Input axis unit vector (IA) x,y,z	0,0,1
1013 SE	13	Mounting point Hinge index, Axis index	
1014 SE	13	First focal plane unit vector (Fp1) x,y,z	
1015 SE	13	Second focal plane unit vector (Fp2) x,y,z	
1016 SE	13	Sun/Star unit vector (Us) x,y,z	
1017 SE	13	Euler Angle Sequence (1-6)	
1018 SE	13	CMG ID number and Gimbal number	
1019 SE	14	Sensor ID number	14
1020 SE	14	Type (G,R,AN,V,P,AC,T,I,SU,ST,IM,P3,V3,CR,CT)	G
1021 SE	14	Mounting point body ID, Mounting point node ID	1,1
1022 SE	14	Second mounting point body ID, Second node ID	
1023 SE	14	Input axis unit vector (IA) x,y,z	1,0,0
1024 SE	14	Mounting point Hinge index, Axis index	
1025 SE	14	First focal plane unit vector (Fp1) x,y,z	
1026 SE	14	Second focal plane unit vector (Fp2) x,y,z	
1027 SE	14	Sun/Star unit vector (Us) x,y,z	
1028 SE	14	Euler Angle Sequence (1-6)	
1029 SE	14	CMG ID number and Gimbal number	
1030 SE	15	Sensor ID number	15
1031 SE	15	Type (G,R,AN,V,P,AC,T,I,SU,ST,IM,P3,V3,CR,CT)	G
1032 SE	15	Mounting point body ID, Mounting point node ID	1,1
1033 SE	15	Second mounting point body ID, Second node ID	
1034 SE	15	Input axis unit vector (IA) x,y,z	0,1,0
1035 SE	15	Mounting point Hinge index, Axis index	
1036 SE	15	First focal plane unit vector (Fp1) x,y,z	
1037 SE	15	Second focal plane unit vector (Fp2) x,y,z	
1038 SE	15	Sun/Star unit vector (Us) x,y,z	
1039 SE	15	Euler Angle Sequence (1-6)	
1040 SE	15	CMG ID number and Gimbal number	
1041 SE	16	Sensor ID number	16
1042 SE	16	Type (G,R,AN,V,P,AC,T,I,SU,ST,IM,P3,V3,CR,CT)	G
1043 SE	16	Mounting point body ID, Mounting point node ID	1,1
1044 SE	16	Second mounting point body ID, Second node ID	
1045 SE	16	Input axis unit vector (IA) x,y,z	0,0,1
1046 SE	16	Mounting point Hinge index, Axis index	
1047 SE	16	First focal plane unit vector (Fp1) x,y,z	
1048 SE	16	Second focal plane unit vector (Fp2) x,y,z	
1049 SE	16	Sun/Star unit vector (Us) x,y,z	
1050 SE	16	Euler Angle Sequence (1-6)	
1051 SE	16	CMG ID number and Gimbal number	
1052 SE	1	Sensor ID number	1

1053 SE	1 Type (G,R,AN,V,P,AC,T,I,SU,ST,IM,P3,V3,CR,CT)	IM
1054 SE	1 Mounting point body ID, Mounting point node ID	1,1
1055 SE	1 Second mounting point body ID, Second node ID	
1056 SE	1 Input axis unit vector (IA) x,y,z	
1057 SE	1 Mounting point Hinge index, Axis index	
1058 SE	1 First focal plane unit vector (Fp1) x,y,z	
1059 SE	1 Second focal plane unit vector (Fp2) x,y,z	
1060 SE	1 Sun/Star unit vector (Us) x,y,z	
1061 SE	1 Euler Angle Sequence (1-6)	1
1062 SE	1 CMG ID number and Gimbal number	
ACTR		
1063 AC	13 Actuator ID number	13
1064 AC	13 Type(J,H,MO,T,B,MA,SG,DG,W,L,M1-M7)	T
1065 AC	13 Actuator location; Node or Hinge (N or H)	
1066 AC	13 Mounting point body ID number, node ID number	
1067 AC	13 Second mounting point body ID, second node ID	
1068 AC	13 Output axis unit vector x,y,z	
1069 AC	13 Mounting point Hinge index, Axis index	13,1
1070 AC	13 Rotor spin axis unit vector x,y,z	
1071 AC	13 Initial rotor momentum, H	
1072 AC	13 Outer gimbal- angle(deg),inertia,friction(D,S,B,N)	
1073 AC	13 Outer gimbal axis unit vector x,y,z	
1074 AC	13 Out gim fric (Tfi,Tgfo,GAM)/(Tfi,M,D,Kf)/(m,M,B,k)	
1075 AC	13 Inner gimbal- angle(deg),inertia,friction(D,S,B,N)	
1076 AC	13 Inner gimbal axis unit vector x,y,z	
1077 AC	13 In gim fric (Tfi,Tgfo,GAM)/(Tfi,M,D,Kf)/(m,M,B,k)	
1078 AC	13 Initial length and rate, y(to) and ydot(to)	
1079 AC	13 Constants; K1 or wo, n or zeta, Kg, Jm	
1080 AC	13 Non-linearities; TLim, Tco, Dz	
1081 AC	23 Actuator ID number	23
1082 AC	23 Type(J,H,MO,T,B,MA,SG,DG,W,L,M1-M7)	T
1083 AC	23 Actuator location; Node or Hinge (N or H)	
1084 AC	23 Mounting point body ID number, node ID number	
1085 AC	23 Second mounting point body ID, second node ID	
1086 AC	23 Output axis unit vector x,y,z	
1087 AC	23 Mounting point Hinge index, Axis index	23,1
1088 AC	23 Rotor spin axis unit vector x,y,z	
1089 AC	23 Initial rotor momentum, H	
1090 AC	23 Outer gimbal- angle(deg),inertia,friction(D,S,B,N)	
1091 AC	23 Outer gimbal axis unit vector x,y,z	
1092 AC	23 Out gim fric (Tfi,Tgfo,GAM)/(Tfi,M,D,Kf)/(m,M,B,k)	
1093 AC	23 Inner gimbal- angle(deg),inertia,friction(D,S,B,N)	
1094 AC	23 Inner gimbal axis unit vector x,y,z	
1095 AC	23 In gim fric (Tfi,Tgfo,GAM)/(Tfi,M,D,Kf)/(m,M,B,k)	
1096 AC	23 Initial length and rate, y(to) and ydot(to)	
1097 AC	23 Constants; K1 or wo, n or zeta, Kg, Jm	
1098 AC	23 Non-linearities; TLim, Tco, Dz	
1099 AC	33 Actuator ID number	33
1100 AC	33 Type(J,H,MO,T,B,MA,SG,DG,W,L,M1-M7)	T
1101 AC	33 Actuator location; Node or Hinge (N or H)	
1102 AC	33 Mounting point body ID number, node ID number	
1103 AC	33 Second mounting point body ID, second node ID	
1104 AC	33 Output axis unit vector x,y,z	
1105 AC	33 Mounting point Hinge index, Axis index	33,1
1106 AC	33 Rotor spin axis unit vector x,y,z	
1107 AC	33 Initial rotor momentum, H	
1108 AC	33 Outer gimbal- angle(deg),inertia,friction(D,S,B,N)	
1109 AC	33 Outer gimbal axis unit vector x,y,z	
1110 AC	33 Out gim fric (Tfi,Tgfo,GAM)/(Tfi,M,D,Kf)/(m,M,B,k)	
1111 AC	33 Inner gimbal- angle(deg),inertia,friction(D,S,B,N)	
1112 AC	33 Inner gimbal axis unit vector x,y,z	
1113 AC	33 In gim fric (Tfi,Tgfo,GAM)/(Tfi,M,D,Kf)/(m,M,B,k)	
1114 AC	33 Initial length and rate, y(to) and ydot(to)	
1115 AC	33 Constants; K1 or wo, n or zeta, Kg, Jm	
1116 AC	33 Non-linearities; TLim, Tco, Dz	
1117 AC	43 Actuator ID number	43
1118 AC	43 Type(J,H,MO,T,B,MA,SG,DG,W,L,M1-M7)	T
1119 AC	43 Actuator location; Node or Hinge (N or H)	
1120 AC	43 Mounting point body ID number, node ID number	

1121 AC	43	Second mounting point body ID, second node ID	
1122 AC	43	Output axis unit vector x,y,z	
1123 AC	43	Mounting point Hinge index, Axis index	43,1
1124 AC	43	Rotor spin axis unit vector x,y,z	
1125 AC	43	Initial rotor momentum, H	
1126 AC	43	Outer gimbal- angle(deg),inertia,friction(D,S,B,N)	
1127 AC	43	Outer gimbal axis unit vector x,y,z	
1128 AC	43	Out gim fric (Tfi,Tgfo,GAM)/(Tfi,M,D,Kf)/(m,M,B,k)	
1129 AC	43	Inner gimbal- angle(deg),inertia,friction(D,S,B,N)	
1130 AC	43	Inner gimbal axis unit vector x,y,z	
1131 AC	43	In gim fric (Tfi,Tgfo,GAM)/(Tfi,M,D,Kf)/(m,M,B,k)	
1132 AC	43	Initial length and rate, y(to) and ydot(to)	
1133 AC	43	Constants; Kl or wo, n or zeta, Kg, Jm	
1134 AC	43	Non-linearities; TLim, Tco, Dz	
1135 AC	53	Actuator ID number	53
1136 AC	53	Type(J,H,MO,T,B,MA,SG,DG,W,L,M1-M7)	T
1137 AC	53	Actuator location; Node or Hinge (N or H)	
1138 AC	53	Mounting point body ID number, node ID number	
1139 AC	53	Second mounting point body ID, second node ID	
1140 AC	53	Output axis unit vector x,y,z	
1141 AC	53	Mounting point Hinge index, Axis index	53,1
1142 AC	53	Rotor spin axis unit vector x,y,z	
1143 AC	53	Initial rotor momentum, H	
1144 AC	53	Outer gimbal- angle(deg),inertia,friction(D,S,B,N)	
1145 AC	53	Outer gimbal axis unit vector x,y,z	
1146 AC	53	Out gim fric (Tfi,Tgfo,GAM)/(Tfi,M,D,Kf)/(m,M,B,k)	
1147 AC	53	Inner gimbal- angle(deg),inertia,friction(D,S,B,N)	
1148 AC	53	Inner gimbal axis unit vector x,y,z	
1149 AC	53	In gim fric (Tfi,Tgfo,GAM)/(Tfi,M,D,Kf)/(m,M,B,k)	
1150 AC	53	Initial length and rate, y(to) and ydot(to)	
1151 AC	53	Constants; Kl or wo, n or zeta, Kg, Jm	
1152 AC	53	Non-linearities; TLim, Tco, Dz	
1153 AC	63	Actuator ID number	63
1154 AC	63	Type(J,H,MO,T,B,MA,SG,DG,W,L,M1-M7)	T
1155 AC	63	Actuator location; Node or Hinge (N or H)	
1156 AC	63	Mounting point body ID number, node ID number	
1157 AC	63	Second mounting point body ID, second node ID	
1158 AC	63	Output axis unit vector x,y,z	
1159 AC	63	Mounting point Hinge index, Axis index	63,1
1160 AC	63	Rotor spin axis unit vector x,y,z	
1161 AC	63	Initial rotor momentum, H	
1162 AC	63	Outer gimbal- angle(deg),inertia,friction(D,S,B,N)	
1163 AC	63	Outer gimbal axis unit vector x,y,z	
1164 AC	63	Out gim fric (Tfi,Tgfo,GAM)/(Tfi,M,D,Kf)/(m,M,B,k)	
1165 AC	63	Inner gimbal- angle(deg),inertia,friction(D,S,B,N)	
1166 AC	63	Inner gimbal axis unit vector x,y,z	
1167 AC	63	In gim fric (Tfi,Tgfo,GAM)/(Tfi,M,D,Kf)/(m,M,B,k)	
1168 AC	63	Initial length and rate, y(to) and ydot(to)	
1169 AC	63	Constants; Kl or wo, n or zeta, Kg, Jm	
1170 AC	63	Non-linearities; TLim, Tco, Dz	
CONTROLLER			
1171 CO	1	Controller ID number	1
1172 CO	1	Controller type (CB,CM,DB,DM,UC,UD)	UD
1173 CO	1	Sample time (sec)	0.064
1174 CO	1	Number of inputs, Number of outputs	6,6
1175 CO	1	Number of states	
1176 CO	1	Output No., Input type (I,S,T), Input ID, Gain	
INTERCONNECT			
1177 IN	13	Interconnect ID number	13
1178 IN	13	Source type(S,C, or F),Source ID,Source row #	C,1,1
1179 IN	13	Destination type(A or C),Dest ID,Dest row #	A,13,1
1180 IN	13	Gain	1
1181 IN	23	Interconnect ID number	23
1182 IN	23	Source type(S,C, or F),Source ID,Source row #	C,1,2
1183 IN	23	Destination type(A or C),Dest ID,Dest row #	A,23,1
1184 IN	23	Gain	1

1185 IN	33	Interconnect ID number	33
1186 IN	33	Source type(S,C, or F),Source ID,Source row #	C,1,3
1187 IN	33	Destination type(A or C),Dest ID,Dest row #	A,33,1
1188 IN	33	Gain	1
1189 IN	43	Interconnect ID number	43
1190 IN	43	Source type(S,C, or F),Source ID,Source row #	C,1,4
1191 IN	43	Destination type(A or C),Dest ID,Dest row #	A,43,1
1192 IN	43	Gain	1
1193 IN	53	Interconnect ID number	53
1194 IN	53	Source type(S,C, or F),Source ID,Source row #	C,1,5
1195 IN	53	Destination type(A or C),Dest ID,Dest row #	A,53,1
1196 IN	53	Gain	1
1197 IN	63	Interconnect ID number	63
1198 IN	63	Source type(S,C, or F),Source ID,Source row #	C,1,6
1199 IN	63	Destination type(A or C),Dest ID,Dest row #	A,63,1
1200 IN	63	Gain	1
1201 IN	1	Interconnect ID number	1
1202 IN	1	Source type(S,C, or F),Source ID,Source row #	S,1,1
1203 IN	1	Destination type(A or C),Dest ID,Dest row #	C,1,1
1204 IN	1	Gain	-1
1205 IN	2	Interconnect ID number	2
1206 IN	2	Source type(S,C, or F),Source ID,Source row #	S,1,2
1207 IN	2	Destination type(A or C),Dest ID,Dest row #	C,1,2
1208 IN	2	Gain	-1
1209 IN	3	Interconnect ID number	3
1210 IN	3	Source type(S,C, or F),Source ID,Source row #	S,1,3
1211 IN	3	Destination type(A or C),Dest ID,Dest row #	C,1,3
1212 IN	3	Gain	-1
1213 IN	4	Interconnect ID number	4
1214 IN	4	Source type(S,C, or F),Source ID,Source row #	S,14,1
1215 IN	4	Destination type(A or C),Dest ID,Dest row #	C,1,4
1216 IN	4	Gain	-1
1217 IN	5	Interconnect ID number	5
1218 IN	5	Source type(S,C, or F),Source ID,Source row #	S,15,1
1219 IN	5	Destination type(A or C),Dest ID,Dest row #	C,1,5
1220 IN	5	Gain	-1
1221 IN	6	Interconnect ID number	6
1222 IN	6	Source type(S,C, or F),Source ID,Source row #	S,16,1
1223 IN	6	Destination type(A or C),Dest ID,Dest row #	C,1,6
1224 IN	6	Gain	-1

CNTDTA

1225 CN	1	CNTDTA : ID Number	1
1226 CN	1	CNTDTA : Number of data values (max = 150)	19
1227 CN	1	CNTDTA : Array value	6.506
1228 CN	1	CNTDTA : Array value	68.382
1229 CN	1	CNTDTA : Array value	72.908
1230 CN	1	CNTDTA : Array value	6.506E-3
1231 CN	1	CNTDTA : Array value	3.419E-2
1232 CN	1	CNTDTA : Array value	3.6454E-2
1233 CN	1	CNTDTA : Array value	325.30
1234 CN	1	CNTDTA : Array value	3419.10
1235 CN	1	CNTDTA : Array value	3645.40
1236 CN	1	CNTDTA : Array value	0.05695
1237 CN	1	CNTDTA : Array value	6.98E-4
1238 CN	1	CNTDTA : Array value	6.98E-4
1239 CN	1	CNTDTA : Array value	0.06
1240 CN	1	CNTDTA : Array value	0.011
1241 CN	1	CNTDTA : Array value	0.01
1242 CN	1	CNTDTA : Array value	1.E6
1243 CN	1	CNTDTA : Array value	1.E6
1244 CN	1	CNTDTA : Array value	1.E6
1245 CN	1	CNTDTA : Array value	0.25

Appendix C **AXAF-I TREETOPS Input File AXAFI.FLN**

FLAG, REVISION NUMBER

XXXXXX

1

BODY ID

2

MODES, NODES, MODAL OPTIONS

6	10	2	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0

NODAL LOCATION VECTORS

```
-0.25659736E-16 0.14245523E+02 0.50299722E-01 0.00000000E+00-0.98421063E-02
0.00000000E+00 0.33627405E+01 0.46979787E+01 0.55389451E-01-0.33627405E+01
0.46979787E+01 0.55389451E-01 0.33627405E+01 0.12000853E+02 0.55389451E-01
-0.33627405E+01 0.12000853E+02 0.55389451E-01 0.33627405E+01 0.19303728E+02
0.55389451E-01-0.33627405E+01 0.19303728E+02 0.55389451E-01 0.33627405E+01
0.26258866E+02 0.55389451E-01-0.33627405E+01 0.26258866E+02 0.55389451E-01
```

MASS, Ixx, Iyy, Izz, Ixy, Ixz, Iyz

```
0.25688829E+01 0.66230670E+03 0.11668189E+02 0.67396022E+03 0.12951566E-15
-0.13009385E-17-0.20111547E+01
```

PHI for node #

2

```
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
```

PHI PRIME for node #

2

```
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
```

PHI for node #

3

```
0.34267600E-05 0.25275900E-02-0.16523000E+00-0.61755500E+00-0.44938300E+00
0.10990500E-01 0.16425400E-01 0.20560500E-03 0.71447400E+00 0.10187200E-04
-0.13720400E-01 0.91569600E+00-0.34107300E-01 0.15257800E-01-0.23861700E+01
0.73277400E-04-0.31646000E-01 0.21297000E+01
```

PHI PRIME for node #

3

```
-0.13447378E+00 0.39621025E-02-0.32939518E-03 0.10671847E-02 0.33307452E-02
0.12957398E+00 0.23957638E+00 0.21752910E+00 0.48884555E-03 0.35746910E+00
0.11949118E-01-0.96766111E-03-0.42796952E+00-0.72856474E+00-0.60992800E-02
0.12530541E+00 0.71339854E-01-0.70710548E-02
```

PHI for node #

4

```
0.31104200E-03 0.80964200E-02-0.15086300E+00-0.59198200E+00-0.25163000E+00
0.57645100E-02 0.25899100E-01-0.59342500E-02 0.37661600E+00 0.91971400E-03
-0.30644700E-01 0.84088200E+00-0.67191500E-01 0.20576800E-01-0.12850500E+01
0.63790800E-02-0.45259300E-01 0.19886400E+01
```

PHI PRIME for node #

4

```
-0.98232809E-01 0.34850594E-02 0.89734909E-03 0.45555262E-02 0.11058862E-02
0.14805712E+00 0.10755706E+00 0.19197648E+00-0.48632905E-02 0.32308772E+00
0.10336061E-01 0.26260770E-02-0.22925957E+00-0.65433337E+00 0.84705268E-02
0.34299412E+00 0.69890076E-01 0.19916117E-01
```

PHI for node #

5

```
0.10511700E-07 0.32662700E-02-0.14734100E+01-0.17949400E+01-0.25219900E+00
0.11283000E-01 0.17730500E-01 0.49816100E-03 0.16398500E+01-0.16279500E-06
-0.39222100E-02 0.28983700E+01-0.97617700E-03 0.58804400E-03-0.22196500E+01
0.63338200E-06-0.16895500E-01 0.71811900E+00
```

PHI PRIME for node #

5

```
-0.18535821E+00-0.60430577E-03 0.00000000E+00 0.13411016E-02 0.59774271E-02
0.00000000E+00 0.12438258E+00 0.86916597E+00 0.00000000E+00-0.20764791E+00
```

```

-0.71677067E-02 0.00000000E+00 0.31649226E+00-0.11764203E+01 0.00000000E+00
-0.86076083E+00-0.10873251E-01 0.00000000E+00
  PHI for node # 6
0.87398000E-04-0.53788900E-02-0.11734000E+01-0.15731800E+01 0.25203600E+00
-0.87900100E-02-0.20435600E-01-0.73059300E-02-0.14277700E+01 0.10382600E-02
-0.64987400E-02 0.31714000E+01 0.67738700E-01-0.87174900E-02 0.26612100E+01
0.12932500E-02-0.49710700E-01 0.20578400E+01
  PHI PRIME for node # 6
-0.16690028E+00-0.17600384E-02 0.82568823E-04-0.79495980E-03 0.47446058E-02
0.14613825E+00-0.14191768E+00 0.75653786E+00 0.13886355E-02 0.47158166E-01
-0.20923077E-01-0.63428297E-03-0.83953918E-01-0.14036001E+01-0.15471379E-02
-0.51644426E+00-0.26030481E-01 0.43785551E-02
  PHI for node # 7
-0.57220400E-07 0.30484500E-02-0.25807200E+01-0.25783200E+01 0.45007500E+00
-0.32329300E-01 0.18981800E-01 0.56736800E-03-0.41307700E+01-0.10577800E-05
-0.11027800E-01 0.11219900E+01-0.24070800E-03-0.28698600E-02-0.86849600E-02
-0.39767100E-06 0.14442900E-01-0.34620400E+01
  PHI PRIME for node # 7
-0.20274931E+00-0.37891396E-03 0.79006480E-05-0.35959918E-03 0.96274811E-02
0.13160566E+00-0.11730541E+00 0.12347534E+01 0.23840994E-03-0.70301572E+00
-0.15140406E-01 0.13899316E-03-0.79412216E+00 0.30577703E-01-0.88140406E-03
0.90810872E+00 0.88912637E-01 0.10373575E-03
  PHI for node # 8
0.58516100E-07 0.30484500E-02-0.25807200E+01-0.25783200E+01-0.45007500E+00
0.32329300E-01 0.18981800E-01-0.56736800E-03 0.41307700E+01 0.10577800E-05
-0.11027800E-01 0.11219900E+01-0.24070800E-03 0.28698600E-02 0.86849600E-02
0.39762000E-06 0.14442900E-01-0.34620400E+01
  PHI PRIME for node # 8
-0.20274931E+00 0.37891396E-03-0.79007200E-05 0.35959918E-03 0.96274811E-02
0.13160566E+00 0.11730541E+00 0.12347534E+01 0.23840994E-03-0.70301572E+00
0.15140406E-01-0.13899316E-03 0.79412216E+00 0.30577703E-01-0.88140406E-03
0.90810872E+00-0.88912637E-01-0.10373575E-03
  PHI for node # 9
0.35819300E-08 0.30484700E-02-0.39931300E+01-0.35094500E+01 0.45004300E+00
-0.34790800E-01 0.17810200E-01 0.56774400E-03-0.48784100E+01 0.69938800E-07
-0.11027400E-01-0.38676400E+01 0.57003100E-02-0.28693600E-02-0.54549700E+01
-0.16194100E-06 0.14442800E-01 0.34909800E+01
  PHI PRIME for node # 9
-0.20356174E+00-0.55587904E-04-0.13330613E-07-0.31879515E-03 0.10342194E-01
0.13387375E+00-0.91133805E-01 0.14489500E+01 0.16844714E-03-0.73649346E+00
-0.15171367E-02-0.38039722E-06-0.71005040E+00 0.16115445E+01-0.85416297E-03
0.11085167E+01 0.43101644E-02 0.11149274E-05
  PHI for node # 10
-0.18157300E-08 0.30484700E-02-0.39931300E+01-0.35094500E+01-0.45004300E+00
0.34790800E-01 0.17810200E-01-0.56774400E-03 0.48784100E+01-0.69819200E-07
-0.11027400E-01-0.38676400E+01 0.57003100E-02 0.28693600E-02 0.54549700E+01
0.16186900E-06 0.14442800E-01 0.34909800E+01
  PHI PRIME for node # 10
-0.20356174E+00 0.55588984E-04 0.13263051E-07 0.31879515E-03 0.10342194E-01
0.13387375E+00 0.91133805E-01 0.14489500E+01 0.16844714E-03-0.73649346E+00
0.15171367E-02 0.38039362E-06 0.71005040E+00 0.16115445E+01-0.85416297E-03
0.11085167E+01-0.43101644E-02-0.11149238E-05
MASS MATRIX
0.120000000E+02 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.12000000E+02 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.12000000E+02 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.12000000E+02
0.00000000E+00 0.12000000E+02 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.12000000E+02 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.12000000E+02
0.12000000E+02
DAMPING MATRIX
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00

```

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0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00
STIFFNESS MATRIX
0.22020840E+02 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.20798280E+03 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.31780320E+03
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.10440012E+04 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.34207440E+04 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.77901960E+04
*** MODAL COUPLING TERMS ***

INTEGRAL PHI DM
-0.16740209E-04 0.29528532E-02 -0.16005450E+01 -0.17375877E+01 0.24947556E-01
0.22243362E-03 0.16911117E-01 0.20343733E-03 0.10254551E+00 0.94073675E-06
-0.85373781E-02 0.72221416E+00 -0.79137993E-02 -0.26541078E-02 0.15777214E+00
-0.24108060E-03 -0.99455802E-02 0.62734730E+00
H PARAMETER
-0.83054904E+02 0.35595343E+00 -0.16330605E-02 0.17008809E-01 -0.22477178E+00
0.84318187E+02 0.43996190E+01 0.28534870E+01 -0.69978860E+00 0.10266543E+02
0.48335086E+00 0.23832211E-02 0.40227323E+01 0.46717960E+01 0.12234931E+00
0.14205193E+02 0.13555315E+01 0.12820144E-01
S1
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
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0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
FLAG, REVISION NUMBER
XXXXXX 1
BODY ID
3
MODES, NODES, MODAL OPTIONS
6 10 2 0 0 0 0 0
0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0
NODAL LOCATION VECTORS
-0.25659736E-16 0.14245523E+02 0.50299722E-01 0.00000000E+00 -0.98421063E-02
0.00000000E+00 0.33627405E+01 0.46979787E+01 0.55389451E-01 -0.33627405E+01
0.46979787E+01 0.55389451E-01 0.33627405E+01 0.12000853E+02 0.55389451E-01
-0.33627405E+01 0.12000853E+02 0.55389451E-01 0.33627405E+01 0.19303728E+02
0.55389451E-01 -0.33627405E+01 0.19303728E+02 0.55389451E-01 0.33627405E+01
0.26258866E+02 0.55389451E-01 -0.33627405E+01 0.26258866E+02 0.55389451E-01
MASS, Ixx, Iyy, Izz, Ixy, Ixz, Iyz
0.25688829E+01 0.66230670E+03 0.11668189E+02 0.67396022E+03 0.12951566E-15
-0.13009385E-17 -0.20111547E+01
PHI for node # 2
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00
PHI PRIME for node # 2
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00
PHI for node # 3
0.34267600E-05 0.25275900E-02 -0.16523000E+00 -0.61755500E+00 -0.44938300E+00
```

0.10990500E-01 0.16425400E-01 0.20560500E-03 0.71447400E+00 0.10187200E-04
 -0.13720400E-01 0.91569600E+00-0.34107300E-01 0.15257800E-01-0.23861700E+01
 0.73277400E-04-0.31646000E-01 0.21297000E+01
 PHI PRIME for node # 3
 -0.13447378E+00 0.39621025E-02-0.32939518E-03 0.10671847E-02 0.33307452E-02
 0.12957398E+00 0.23957638E+00 0.21752910E+00 0.48884555E-03 0.35746910E+00
 0.11949118E-01-0.96766111E-03-0.42796952E+00-0.72856474E+00-0.60992800E-02
 0.12530541E+00 0.71339854E-01-0.70710548E-02
 PHI for node # 4
 0.31104200E-03 0.80964200E-02-0.15086300E+00-0.59198200E+00-0.25163000E+00
 0.57645100E-02 0.25899100E-01-0.59342500E-02 0.37661600E+00 0.91971400E-03
 -0.30644700E-01 0.84088200E+00-0.67191500E-01 0.20576800E-01-0.12850500E+01
 0.63790800E-02-0.45259300E-01 0.19886400E+01
 PHI PRIME for node # 4
 -0.98232809E-01 0.34850594E-02 0.89734909E-03 0.45555262E-02 0.11058862E-02
 0.14805712E+00 0.10755706E+00 0.19197648E+00-0.48632905E-02 0.32308772E+00
 0.10336061E-01 0.26260770E-02-0.22925957E+00-0.65433337E+00 0.84705268E-02
 0.34299412E+00 0.69890076E-01 0.19916117E-01
 PHI for node # 5
 0.10511700E-07 0.32662700E-02-0.14734100E+01-0.17949400E+01-0.25219900E+00
 0.11283000E-01 0.17730500E-01 0.49816100E-03 0.16398500E+01-0.16279500E-06
 -0.39222100E-02 0.28983700E+01-0.97617700E-03 0.58804400E-03-0.22196500E+01
 0.63338200E-06-0.16895500E-01 0.71811900E+00
 PHI PRIME for node # 5
 -0.18535821E+00-0.60430577E-03 0.00000000E+00 0.13411016E-02 0.59774271E-02
 0.00000000E+00 0.12438258E+00 0.86916597E+00 0.00000000E+00-0.20764791E+00
 -0.71677067E-02 0.00000000E+00 0.31649226E+00-0.11764203E+01 0.00000000E+00
 -0.86076083E+00-0.10873251E-01 0.00000000E+00
 PHI for node # 6
 0.87398000E-04-0.53788900E-02-0.11734000E+01-0.15731800E+01 0.25203600E+00
 -0.87900100E-02-0.20435600E-01-0.73059300E-02-0.14277700E+01 0.10382600E-02
 -0.64987400E-02 0.31714000E+01 0.67738700E-01-0.87174900E-02 0.26612100E+01
 0.12932500E-02-0.49710700E-01 0.20578400E+01
 PHI PRIME for node # 6
 -0.16690028E+00-0.17600384E-02 0.82568823E-04-0.79495980E-03 0.47446058E-02
 0.14613825E+00-0.14191768E+00 0.75653786E+00 0.13886355E-02 0.47158166E-01
 -0.20923077E-01-0.63428297E-03-0.83953918E-01-0.14036001E+01-0.15471379E-02
 -0.51644426E+00-0.26030481E-01 0.43785551E-02
 PHI for node # 7
 -0.57220400E-07 0.30484500E-02-0.25807200E+01-0.25783200E+01 0.45007500E+00
 -0.32329300E-01 0.18981800E-01 0.56736800E-03-0.41307700E+01-0.10577800E-05
 -0.11027800E-01 0.11219900E+01-0.24070800E-03-0.28698600E-02-0.86849600E-02
 -0.39767100E-06 0.14442900E-01-0.34620400E+01
 PHI PRIME for node # 7
 -0.20274931E+00-0.37891396E-03 0.79006480E-05-0.35959918E-03 0.96274811E-02
 0.13160566E+00-0.11730541E+00 0.12347534E+01 0.23840994E-03-0.70301572E+00
 -0.15140406E-01 0.13899316E-03-0.79412216E+00 0.30577703E-01-0.88140406E-03
 0.90810872E+00 0.88912637E-01 0.10373575E-03
 PHI for node # 8
 0.58516100E-07 0.30484500E-02-0.25807200E+01-0.25783200E+01-0.45007500E+00
 0.32329300E-01 0.18981800E-01-0.56736800E-03 0.41307700E+01 0.10577800E-05
 -0.11027800E-01 0.11219900E+01-0.24070800E-03 0.28698600E-02 0.86849600E-02
 0.39762000E-06 0.14442900E-01-0.34620400E+01
 PHI PRIME for node # 8
 -0.20274931E+00 0.37891396E-03-0.79007200E-05 0.35959918E-03 0.96274811E-02
 0.13160566E+00 0.11730541E+00 0.12347534E+01 0.23840994E-03-0.70301572E+00
 0.15140406E-01-0.13899316E-03 0.79412216E+00 0.30577703E-01-0.88140406E-03
 0.90810872E+00-0.88912637E-01-0.10373575E-03
 PHI for node # 9
 0.35819300E-08 0.30484700E-02-0.39931300E+01-0.35094500E+01 0.45004300E+00
 -0.34790800E-01 0.17810200E-01 0.56774400E-03-0.48784100E+01 0.69938800E-07
 -0.11027400E-01-0.38676400E+01 0.57003100E-02-0.28693600E-02-0.54549700E+01
 -0.16194100E-06 0.14442800E-01 0.34909800E+01
 PHI PRIME for node # 9
 -0.20356174E+00-0.55587904E-04-0.13330613E-07-0.31879515E-03 0.10342194E-01
 0.13387375E+00-0.91133805E-01 0.14489500E+01 0.16844714E-03-0.73649346E+00
 -0.15171367E-02-0.38039722E-06-0.71005040E+00 0.16115445E+01-0.85416297E-03

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0.11085167E+01 0.43101644E-02 0.11149274E-05
PHI for node # 10
-0.18157300E-08 0.30484700E-02-0.39931300E+01-0.35094500E+01-0.45004300E+00
0.34790800E-01 0.17810200E-01-0.56774400E-03 0.48784100E+01-0.69819200E-07
-0.11027400E-01-0.38676400E+01 0.57003100E-02 0.28693600E-02 0.54549700E+01
0.16186900E-06 0.14442800E-01 0.34909800E+01
PHI PRIME for node # 10
-0.20356174E+00 0.55588984E-04 0.13263051E-07 0.31879515E-03 0.10342194E-01
0.13387375E+00 0.91133805E-01 0.14489500E+01 0.16844714E-03-0.73649346E+00
0.15171367E-02 0.38039362E-06 0.71005040E+00 0.16115445E+01-0.85416297E-03
0.11085167E+01-0.43101644E-02-0.11149238E-05
MASS MATRIX
0.12000000E+02 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.12000000E+02 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.12000000E+02
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.12000000E+02 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.12000000E+02 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.12000000E+02
DAMPING MATRIX
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00
STIFFNESS MATRIX
0.22020840E+02 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.20798280E+03 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.31780320E+03
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.10440012E+04 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.34207440E+04 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.77901960E+04
*** MODAL COUPLING TERMS ***

INTEGRAL PHI DM
-0.16740209E-04 0.29528532E-02-0.16005450E+01-0.17375877E+01 0.24947556E-01
0.22243362E-03 0.16911117E-01 0.20343733E-03 0.10254551E+00 0.94073675E-06
-0.85373781E-02 0.72221416E+00-0.79137993E-02-0.26541078E-02 0.15777214E+00
-0.24108060E-03-0.99455802E-02 0.62734730E+00
H PARAMETER
-0.83054904E+02 0.35595343E+00-0.16330605E-02 0.17008809E-01-0.22477178E+00
0.84318187E+02 0.43996190E+01 0.28534870E+01-0.69978860E+00 0.10266543E+02
0.48335086E+00 0.23832211E-02 0.40227323E+01 0.46717960E+01 0.12234931E+00
0.14205193E+02 0.13555315E+01 0.12820144E-01
S1
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00
0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00 0.00000000E+00

```

Appendix D
AXAF-I TREETOPS Input File AXAFI.RET

2 6
1 2 3 4 5 6
3 6
1 2 3 4 5 6

Appendix E

NASTRAN Model of AXAF-I Solar Array

```

NASTRAN TITLEOPT=-1
ID AXAF,DEPLOYED ED12
$SOL 103
SOL 3
TIME 200
$$YK DIAG 8,9,13,14
diag 8,9
readfile ALTERS
$$$$$$$$$ by YK
$ALTER 105 $ FOR '91 CSA NASTRAN
$ALTER 106 $ FOR '93 CSA NASTRAN
RFINSERT READ $ FOR '94 CSA NASTRAN
TABPT EQEXIN// $
GKAM , ,PHIA,MI,LAMA,DIT,,,CASECC/MMASS,MDAMP,MSTIFF,PHIDH/-1/
0/0.0/1.E+30/-1/-1/-1/V,N,NONCUP/V,N,FMODE/ $
VECPLOT, ,BGPDT,EQEXIN,CSTM,,/RBMAT1///4 $
TRNSP RBMAT1/RBMAT $
MATGEN ,/ZEROG/7/LUSET/1 $
VECPLOT ZEROG,BGPDT,EQEXIN,CSTM,CASECC,/COORD///3 $
MATGEN ,/PVECX/4/1/LUSET/0/1/6/1 $
MATGEN ,/PVECY/4/1/LUSET/0/1/6/2 $
MATGEN ,/PVE CZ/4/1/LUSET/0/1/6/3 $
MATGEN ,/PVE CXY/6/2/1/1 $
MATGEN ,/PVE CXYZ/6/3/2/1 $
PARTN COORD,,PVECX/,XGEOM,,/1 $
PARTN COORD,,PVECY/,YGEOM,,/1 $
PARTN COORD,,PVE CZ/,ZGEOM,,/1 $
MERGE XGEOM,,YGEOM,,PVE CXY,/XYZGEO/1 $
MERGE XYZGEO,,ZGEOM,,PVE CXYZ,/XYZGEO/1 $
UMERGE USET,PHIA,/PHIAJB/C,Y,MAJOR=N/C,Y,SUB0=A/C,Y,SUB1=SB $
OUTPUT5 MGG,PHIAJB,MMASS,MSTIFF,XYZGEO//C,N,-1/C,N,11/C,N,DYNAC SJB/1 $ $
OUTPUT5 ,,,,/C,N,-9/C,N,11/C,N,DYNAC SJB/C,N,1 $
ENDALTER $
$$$$$$$$$
CEND
$
$
$ RECIEVED FROM TRW/ZIGGY JAB 3/2/93
$
$-----
$ necessary alter for Lanczos with sol 3
$COMPILE SOL3 SOUIN=MSCSOU
$RFALTER RF3D83
$-----
LINE=48
TITLE = AXAF-I Solar Array Modes
SUBTITLE = Normal Modal Analysis
$LABEL = FREE-FREE
$$YK DISPLACEMENT = ALL
disp (plot) = all $ YK
$
$$YK ECHO = SORT
echo = none $ YK
SPC=100
$MPC=10
METHOD = 1000
$SET 1 = ALL

```



```

$SET 1 = 63001,60000,60003,60400,60403,60800,60803,61100,61103
$DISP = 1
$
$
$
$PLOTID = SEND PLOTS TO J. A. BRUNTY BIN 196
OUTPUT(PLOT)
$PLOTTER NAST
$SET 1 = 1 THRU 1000000
SET 1 = ALL
$SET 1 = 63001,60000,60003,60400,60403,60800,60803,61100,61103
$MAXIMUM DEFORMATION 100.
CSCALE=2
AXES X,Y,Z
VIEW 5.,35.,10.
FIND SCALE, ORIGIN 1, SET 1
PLOT SET 1, ORIGIN 1
PLOT SET 1, ORIGIN 1, LABEL GRID POINTS
$PLOT SET 1, ORIGIN 1, LABEL ELEMENTS
PLOT MODAL DEFORMATION, SET 1, ORIGIN 1
$-----
BEGIN BULK
param autospc yes
PARAM GRDPNT 0
PARAM WTMASS .002588
PARAM TINY 1.0
$PARAM K6ROT 0.25
$ FOR OUTPUT USED IN MSC/NASTRAN EXCEL
$PARAM POST 0
$ FOR OUTPUT USED IN PATRAN
PARAM,POST,-1
$ PARAM DEFAULT IS 1
$PARAM,POST,1
$-----2-----3-----4-----5-----6-----7-----8-----9-----
$EIGRL 1000 -1.0 100.
$$YK EIGR 1000 BLAN -1. 100.
EIGR 1000 BLAN -1. 20.
$-----
$INCLUDE sa+yscif.osas
$
$ SADA REPRESENTED WITH A RIGID TEPEE TO PROVIDE INTERFACE
$ AT THE PROPER LOCATION AND CELAS TO PROVIDE FOR SADA
$ FLEXIBILITIES. HRG 3/30/94
$
$ Material properties of tipee CBARS. OSAS. (Uncomment only if the wing
is to be run alone.)
$
$$$PBAR 872 809 100. 1000. 1000. 2000.
$$MAT1 809 10.0E06 .33
$
$$$CBAR 87201 872 84023 84501 0. 0. 1.
+C942219
$$$CBAR 87202 872 84024 84501 0. 0. 1.
+C942220
$$$CBAR 87203 872 84027 84501 0. 0. 1.
+C942419
$$$CBAR 87204 872 84028 84501 0. 0. 1.
+C942420
$$$CBAR 87205 872 84031 84501 0. 0. 1.
+C942619
$$$CBAR 87206 872 84032 84501 0. 0. 1.
+C942620
$
$ COINCIDENT GRIDS TO MODEL SADA FLEXIBILITY FOR +Y SA
$
$*****
***

```

```

$      Uncomment coordinate system 810 if this panel is to be run alone.  OSAS.
$
CORD2R  810      0      0.0      0.0      0.0      0.0      0.0      1.
        1.      0.0      0.0
$*****
***
$
$$$GRID   84501   810      445.88  68.025  -9.53
$$$GRID   84502   810      445.88  68.025  -9.53
$$$GRID   84503   810      445.88  68.025  -9.53 COMMENTED OUT PER R.H. .
OSAS. 5/24/94.
$GRID    84504   810      445.88  68.025  -9.53
$
$  SADA STIFFNESS (TDRS VALUES)
$
$$$CELAS2 89235   50.00E3 84501   1      84502   1
$$$CELAS2 89236   50.00E3 84501   2      84502   2
$$$CELAS2 89237   50.00E3 84501   3      84502   3
$$$CELAS2 89238   8.00E5  84501   4      84502   4
$$$CELAS2 89239   8.00E4  84501   5      84502   5
$$$CELAS2 89240   8.00E5  84501   6      84502   6
$
$!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
$  Include rigid elements for free-free run only
$
$RBE2     80000      87064  123456  87060  87036  87040  87037  87039
$      84504
$!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
$
$  Bottom grids of tepee
$
$$$GRID   84023   810      450.113 60.25  -4.53
$$$GRID   84024   810      440.113 60.25  -4.53
$$$GRID   84027   810      450.113 60.25  -9.53
$$$GRID   84028   810      440.113 60.25  -9.53
$$$GRID   84031   810      450.113 60.25 -14.53
$$$GRID   84032   810      440.113 60.25 -14.53
$
$INCLUDE sa+y.osas
$
$$$ BASIC COORDINATE SYSTEM of S/A (600) FOR MODEL
$
$
$  Attachement of +y wing to tepee (corner grid of yoke to outboard grid of
SADA)
$
$$$RBAR    60001  84502  63001  123456      123456
spc1,100,12346,63001
$
$  Modify Location of I/F per IOC M533.2.94-073
$  RH 5/94
GRID    63001   600      0.      -.11811 0.0      600
$$$GRID   63001   810      445.88  68.025  -9.53
$
RBE2    63051   63001  123456  63002
GRID    63002   600      0.      .94488 0.0      600
GRID    63003   600      0.      .94488 0.0      600
$
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$  BAPTA & SADM Hinge
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$
RBE2    63052   63002  123      63003
CELAS2  63061   2.3454+563002  4      63003  4
CELAS2  63062   5.8414+463002  5      63003  5
CELAS2  63063   1.6374+663002  6      63003  6
$

```

```

CONM2    63071    63003    600      2.82368
$
$
$
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$      Inboard Panel
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$      Edge Beams
CBAR      60151      611      60000      60001      0.      0.      1.
CBAR      60152      611      60001      60002      0.      0.      1.
CBAR      60153      611      60002      60003      0.      0.      1.
CBAR      60154      611      60300      60301      0.      0.      1.
CBAR      60155      611      60301      60302      0.      0.      1.
CBAR      60156      611      60302      60303      0.      0.      1.
$      Panel Wt
CONM2      60161      60001      601      0.12346
CONM2      60162      60002      601      0.12346
CONM2      60163      60301      601      0.12346
CONM2      60164      60302      601      0.12346
CONM2      60165      60101      601      0.1411
CONM2      60166      60102      601      0.1411
CONM2      60167      60201      601      0.1411
CONM2      60168      60202      601      0.1411
$      Quad's
CQUAD4      60101      601      60000      60001      60101      60100
CQUAD4      60102      602      60001      60002      60102      60101
CQUAD4      60103      601      60002      60003      60103      60102
CQUAD4      60104      601      60100      60101      60201      60200
CQUAD4      60105      602      60101      60102      60202      60201
CQUAD4      60106      601      60102      60103      60203      60202
CQUAD4      60107      601      60200      60201      60301      60300
CQUAD4      60108      602      60201      60202      60302      60301
CQUAD4      60109      601      60202      60203      60303      60302
$      Grids
GRID      60000      601      40.3545 0.0      0.0      601
GRID      60001      601      22.6379 0.0      0.0      601
GRID      60002      601      -22.6379 0.0      0.0      601
GRID      60003      601      -40.3545 0.0      0.0      601
GRID      60100      601      40.3545 20.8466 0.0      601
GRID      60101      601      22.6379 20.8466 0.0      601
GRID      60102      601      -22.6379 20.8466 0.0      601
GRID      60103      601      -40.3545 20.8466 0.0      601
GRID      60200      601      40.3545 65.8271 0.0      601
GRID      60201      601      22.6379 65.8271 0.0      601
GRID      60202      601      -22.6379 65.8271 0.0      601
GRID      60203      601      -40.3545 65.8271 0.0      601
GRID      60300      601      40.3545 83.465 0.0      601
GRID      60301      601      22.6379 83.465 0.0      601
GRID      60302      601      -22.6379 83.465 0.0      601
GRID      60303      601      -40.3545 83.465 0.0      601
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$      Mid Panel
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$      Edge Beams
CBAR      60251      611      60400      60401      0.      0.      1.
CBAR      60252      611      60401      60402      0.      0.      1.
CBAR      60253      611      60402      60403      0.      0.      1.
CBAR      60254      611      60700      60701      0.      0.      1.
CBAR      60255      611      60701      60702      0.      0.      1.
CBAR      60256      611      60702      60703      0.      0.      1.
$      Panel Wt
CONM2      60261      60401      602      0.12346
CONM2      60262      60402      602      0.12346
CONM2      60263      60701      602      0.12346
CONM2      60264      60702      602      0.12346

```

CONM2	60265	60501	602	0.1411		
CONM2	60266	60502	602	0.1411		
CONM2	60267	60601	602	0.1411		
CONM2	60268	60602	602	0.1411		
\$ Quads						
CQUAD4	60201	601	60400	60401	60501	60500
CQUAD4	60202	602	60401	60402	60502	60501
CQUAD4	60203	601	60402	60403	60503	60502
CQUAD4	60204	601	60500	60501	60601	60600
CQUAD4	60205	602	60501	60502	60602	60601
CQUAD4	60206	601	60502	60503	60603	60602
CQUAD4	60207	601	60600	60601	60701	60700
CQUAD4	60208	602	60601	60602	60702	60701
CQUAD4	60209	601	60602	60603	60703	60702
\$ Grids						
GRID	60400	602	40.3545	0.0	0.0	602
GRID	60401	602	22.6379	0.0	0.0	602
GRID	60402	602	-22.6379	0.0	0.0	602
GRID	60403	602	-40.3545	0.0	0.0	602
GRID	60500	602	40.3545	17.6379	0.0	602
GRID	60501	602	22.6379	17.6379	0.0	602
GRID	60502	602	-22.6379	17.6379	0.0	602
GRID	60503	602	-40.3545	17.6379	0.0	602
GRID	60600	602	40.3545	62.6184	0.0	602
GRID	60601	602	22.6379	62.6184	0.0	602
GRID	60602	602	-22.6379	62.6184	0.0	602
GRID	60603	602	-40.3545	62.6184	0.0	602
GRID	60700	602	40.3545	83.465	0.0	602
GRID	60701	602	22.6379	83.465	0.0	602
GRID	60702	602	-22.6379	83.465	0.0	602
GRID	60703	602	-40.3545	83.465	0.0	602
\$						
\$						
\$						
\$ Outboard Panel						
\$						
\$ Edge Beams						
CBAR	60351	611	60800	60801	0.	0. 1.
CBAR	60352	611	60801	60802	0.	0. 1.
CBAR	60353	611	60802	60803	0.	0. 1.
CBAR	60354	611	61100	61101	0.	0. 1.
CBAR	60355	611	61101	61102	0.	0. 1.
CBAR	60356	611	61102	61103	0.	0. 1.
\$ Panel Wt						
CONM2	60361	60801	603	0.12346		
CONM2	60362	60802	603	0.12346		
CONM2	60363	61101	603	0.12346		
CONM2	60364	61102	603	0.12346		
CONM2	60365	60901	603	0.54586		
CONM2	60366	60902	603	0.54586		
CONM2	60367	61001	603	0.54586		
CONM2	60368	61002	603	0.54586		
\$ Tip Masses for Outboard Panel						
CONM2	60369	61100	603	0.26		
CONM2	60370	61103	603	0.26		
\$ Quads						
CQUAD4	60301	601	60800	60801	60901	60900
CQUAD4	60302	602	60801	60802	60902	60901
CQUAD4	60303	601	60802	60803	60903	60902
CQUAD4	60304	601	60900	60901	61001	61000
CQUAD4	60305	602	60901	60902	61002	61001
CQUAD4	60306	601	60902	60903	61003	61002
CQUAD4	60307	601	61000	61001	61101	61100
CQUAD4	60308	602	61001	61002	61102	61101
CQUAD4	60309	601	61002	61003	61103	61102
\$ Grids						
GRID	60800	603	40.3545	0.0	0.0	603

GRID	60801	603	22.6379	0.0	0.0	603
GRID	60802	603	-22.6379	0.0	0.0	603
GRID	60803	603	-40.3545	0.0	0.0	603
GRID	60900	603	40.3545	20.8466	0.0	603
GRID	60901	603	22.6379	20.8466	0.0	603
GRID	60902	603	-22.6379	20.8466	0.0	603
GRID	60903	603	-40.3545	20.8466	0.0	603
GRID	61000	603	40.3545	65.8271	0.0	603
GRID	61001	603	22.6379	65.8271	0.0	603
GRID	61002	603	-22.6379	65.8271	0.0	603
GRID	61003	603	-40.3545	65.8271	0.0	603
GRID	61100	603	40.3545	83.465	0.0	603
GRID	61101	603	22.6379	83.465	0.0	603
GRID	61102	603	-22.6379	83.465	0.0	603
GRID	61103	603	-40.3545	83.465	0.0	603
\$						
\$						
\$ Yoke						
\$						
\$						
GRID	63004	600	-6.715	16.1516	0.0	600
GRID	63005	600	-13.4307	31.3582	70.0	600
GRID	63006	600	-18.0335	41.7815	0.0	600
GRID	63007	600	-22.6378	52.2047	0.0	600
GRID	63008	600	6.715	16.1516	0.0	600
GRID	63009	600	13.4307	31.3582	70.0	600
GRID	63010	600	18.0335	41.7815	0.0	600
GRID	63011	600	22.6378	52.2047	0.0	600
\$ Yoke Cross Bar						
GRID	63012	600	-11.3189	52.2047	0.0	600
GRID	63013	600	0.	52.2047	0.0	600
GRID	63014	600	11.3189	52.2047	0.0	600
\$						
CBAR	63001	612	63003	63004	0.	0. 1.
63002	612	63004	63005	0.	0.	1.
CBAR	63003	612	63005	63006	0.	0. 1.
CBAR	63004	612	63006	63007	0.	0. 1.
CBAR	63005	612	63003	63008	0.	0. 1.
CBAR	63006	612	63008	63009	0.	0. 1.
CBAR	63007	612	63009	63010	0.	0. 1.
CBAR	63008	612	63010	63011	0.	0. 1.
\$ Yoke Cross Bar						
CBAR	63009	613	63007	63012	0.	0. 1.
CBAR	63010	613	63012	63013	0.	0. 1.
CBAR	63011	613	63013	63014	0.	0. 1.
CBAR	63012	613	63014	63011	0.	0. 1.
\$						
\$						
\$ Hinge Lines						
\$						
\$ Yoke to Wing I/F						
\$						
CBAR	63101	614	63007	63101	1.	0. 0.
CBAR	63102	615	63102	60002	1.	0. 0.
CBAR	63103	614	63011	63103	1.	0. 0.
CBAR	63104	615	63104	60001	1.	0. 0.
GRID	63101	601	-22.6378	-2.0866	0.5953	601
GRID	63102	601	-22.6378	-2.0866	0.5953	601
GRID	63103	601	22.6378	-2.0866	0.5953	601
GRID	63104	601	22.6378	-2.0866	0.5953	601
RBE2	63105	63101	123456	63102		
RBE2	63106	63103	123456	63104		
\$ Inbd to Mid						
CBAR	63111	615	60302	63111	1.	0. 0.
CBAR	63112	615	63112	60402	1.	0. 0.
CBAR	63113	615	60301	63113	1.	0. 0.
CBAR	63114	615	63114	60401	1.	0. 0.

```

GRID    63111    602    -22.6378-2.0866 -.5953    602
GRID    63112    602    -22.6378-2.0866 -.5953    602
GRID    63113    602    22.6378 -2.0866 -.5953    602
GRID    63114    602    22.6378 -2.0866 -.5953    602
RBE2    63115    63111  123456    63112
RBE2    63116    63113  123456    63114
$      Outbd to Mid
CBAR    63121    615    60702    63121    1.      0.      0.
CBAR    63122    615    63122    60802    1.      0.      0.
CBAR    63123    615    60701    63123    1.      0.      0.
CBAR    63124    615    63124    60801    1.      0.      0.
GRID    63121    603    -22.6378-2.0866 0.5953    603
GRID    63122    603    -22.6378-2.0866 0.5953    603
GRID    63123    603    22.6378 -2.0866 0.5953    603
GRID    63124    603    22.6378 -2.0866 0.5953    603
RBE2    63125    63121  123456    63122
RBE2    63126    63123  123456    63124
$
$
$
$
$
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$      Coordinate Systems
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$
CORD2R   600          0.      0.      0.      0.      0.      1.      +C600
+C600    1.      0.      0.
$$$CORD2R   600          445.88  68.025  -9.53   445.88  68.025  -8.53
+C600
$$$+C600    446.88  68.025  -9.53
CORD2R   601          600      0.      56.378  0.6647  0.      56.378  1.      +C601
+C601    1.      56.378  0.6647
CORD2R   602          601      0.      87.6382  0.      0.      87.6382  1.      +C602
+C602    1.      87.6382  0.
CORD2R   603          602      0.      87.6382  0.      0.      87.6382  1.      +C603
+C603    1.      87.6382  0.
$
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$      Materials and Properties
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$
MAT1     614          8.238+6 3.133+6
MAT1     615          8.238+6 3.133+6
MAT1     623          1.218+4
MAT1     631          2.2336+77.542+6
MAT1     632          1.3779+74.6412+6
MAT1     633          2.64+7  1.0153+6
MAT2     621          2.226+7 3.168+5 0.      2.226+7 0.      5.802+5 0.      +MT2A
+MT2A    .324-6  .324-6  0.      68.
MAT2     622          1.8710+74.6593+50.      2.5824+70.      5.802+5 0.      +MT2B
+MT2B    .324-6  .324-6  0.      68.
PBAR     611          631      7.44-3  1.2013-21.3935-34.5648-3
PBAR     612          632      .2294  8.1188-28.1188-2.121694 3.3246-2
PBAR     613          633      6.8045-21.2978-2.130878 1.1396-62.824-2
PBAR     614          614      .15655 1.946-3 5.237-3 7.616-3 .11759
PBAR     615          615      .15655 1.946-3 6.979-3 7.616-3 .13236
PSHELL   601          621      9.449-3 621      25484. 623      91.67  2.8702-3+PS601
+PS601   .4378    -.4378
PSHELL   602          622      1.1811-2622      16354.1 623      73.33  3.587-3 +PS602
+PS602   .438976 -.438976
$
$
$
ENDDATA

```

Appendix F

NASTRAN Normal Modal Analysis Output of AXAF-I Solar Array

NORMAL MODAL ANALYSIS

OUTPUT FROM GRID POINT WEIGHT GENERATOR
REFERENCE POINT = 0

MO - RIGID BODY MASS MATRIX IN BASIC COORDINATE SYSTEM

```
***
* 8.271776E+01 0.000000E+00 0.000000E+00 0.000000E+00 4.993016E+01 -1.414086E+04 *
* 0.000000E+00 8.271776E+01 0.000000E+00 -4.993016E+01 0.000000E+00 6.863821E-13 *
* 0.000000E+00 0.000000E+00 8.271776E+01 1.414086E+04 -2.745528E-12 0.000000E+00 *
* 0.000000E+00 -4.993016E+01 1.414086E+04 3.071223E+06 -7.028553E-10 -1.029573E-12 *
* 4.993016E+01 0.000000E+00 -6.863821E-13 -3.514276E-10 5.410720E+04 -9.326042E+03 *
* -1.414086E+04 6.863821E-13 0.000000E+00 -2.745528E-12 -9.326042E+03 3.125262E+06 *
***
```

S - TRANSFORMATION MATRIX FOR SCALAR MASS PARTITION

```
***
* 1.000000E+00 0.000000E+00 0.000000E+00 *
* 0.000000E+00 1.000000E+00 0.000000E+00 *
* 0.000000E+00 0.000000E+00 1.000000E+00 *
***
```

DIRECTION	MASS	X-C.G.	Y-C.G.	Z-C.G.
MASS AXIS SYSTEM (S)				
X	8.271776E+01	0.000000E+00	1.709532E+02	6.036208E-01
Y	8.271776E+01	8.297881E-15	0.000000E+00	6.036208E-01
Z	8.271776E+01	3.319152E-14	1.709532E+02	0.000000E+00

I(S) - INERTIAS RELATIVE TO C.G.

```
***
* 6.537670E+05 2.334984E-10 6.152586E-13 *
* 2.334984E-10 5.407706E+04 7.903221E+02 *
* 6.152586E-13 7.903221E+02 7.078363E+05 *
***
```

I(Q) - PRINCIPAL INERTIAS

```
***
* 6.537670E+05 *
* 7.078372E+05 *
* 5.407610E+04 *
***
```

Q - TRANSFORMATION MATRIX

$I(Q) = QT \cdot IBAR(S) \cdot Q$

```
***
* 1.000000E+00 0.000000E+00 0.000000E+00 *
* 0.000000E+00 1.208886E-03 9.999993E-01 *
* 0.000000E+00 -9.999993E-01 1.208886E-03 *
***
```

AXAF-I SOLAR ARRAY
NORMAL MODAL ANALYSIS

R E A L E I G E N V A L U E S

MODE NO.	EXTRACTION ORDER	EIGENVALUE	RADIAN FREQUENCY	CYCLIC FREQUENCY	GENERALIZ MASS	GENERALIZED STIFFNESS
1	1	1.835065E+00	1.354646E+00	2.155986E-01	1.000000E+00	1.835065E+00
2	2	1.733193E+01	4.163164E+00	6.625881E-01	1.000000E+00	1.733193E+01
3	3	2.648359E+01	5.146221E+00	8.190466E-01	1.000000E+00	2.648359E+01
4	4	8.700010E+01	9.327385E+00	1.484499E+00	1.000000E+00	8.700010E+01
5	5	2.850619E+02	1.688378E+01	2.687136E+00	1.000000E+00	2.850619E+02
6	6	6.491830E+02	2.547907E+01	4.055120E+00	1.000000E+00	6.491830E+02
7	7	1.019662E+03	3.193215E+01	5.082160E+00	1.000000E+00	1.019662E+03
8	8	2.025334E+03	4.500371E+01	7.162563E+00	1.000000E+00	2.025334E+03
9	9	2.203281E+03	4.693912E+01	7.470593E+00	1.000000E+00	2.203281E+03
10	10	1.468234E+04	1.211707E+02	1.928492E+01	1.000000E+00	1.468234E+04

Appendix G

SSE MACOS Input File

```

ChfRayDir= 0.000000000D+00 0.000000000D+00 1.000000000D+00
ChfRayPos= 0.000000000D+00 0.000000000D+00 -1.000000000D+01
zSource= 1.000000000D+22
IndRef= 1.000000000D+00
Extinc= 0.000000000D+00
Wavelen= 2.834700000D-05
Flux= 1.000000000D+00
GridType= Circular
Aperture= 17.2
Obscratn= 0.000000000D+00
nGridpts= 100
xGrid= 1.000000000D+00 0.000000000D+00 0.000000000D+00
yGrid= 0.000000000D+00 1.000000000D+00 0.000000000D+00
nElt= 9

    iElt= 1
    EltName= ring_front
    Element= Refractor
    Surface= Flat
    KrElt= -1.000000000D+22
    KcElt= 0.000000000D+00
    psiElt= 0.000000000D+00 0.000000000D+00 -1.000000000D+00
    VptElt= 0.000000000D+00 0.000000000D+00 -1.377730000D+00
    RptElt= 0.000000000D+00 0.000000000D+00 -1.377730000D+00
    IndRef= 1.595059000D+00
    Extinc= 0.000000000D+00
    nObs= 1
    ObsType= Circle
    ObsVec= 7.190000000D+00 0.000000000D+00 0.000000000D+00
    xObs= 1.000000000D+00 0.000000000D+00 0.000000000D+00
    ApType= Circular
    ApVec= 7.590000000D+00 0.000000000D+00 0.000000000D+00
    zElt= 1.000000000D+22
    PropType= Geometric
    nECoord= -6

    iElt= 2
    EltName= ring_back
    Element= Refractor
    Surface= Aspheric
    KrElt= 1.337423000D+01
    KcElt= 0.000000000D+00
    psiElt= 0.000000000D+00 0.000000000D+00 -1.000000000D+00
    VptElt= 0.000000000D+00 0.000000000D+00 -1.374730000D+00
    RptElt= 0.000000000D+00 0.000000000D+00 -1.374730000D+00
    IndRef= 1.000000000D+00
    Extinc= 0.000000000D+00
    AsphCoef= 4.145520000D-04 -3.444760000D-06 1.990750000D-08 0.000000000D+00
    nObs= 1
    ObsType= Circle
    ObsVec= 7.190000000D+00 0.000000000D+00 0.000000000D+00
    xObs= 1.000000000D+00 0.000000000D+00 0.000000000D+00
    ApType= Circular
    ApVec= 7.590000000D+00 0.000000000D+00 0.000000000D+00
    zElt= 1.337423000D+01
    PropType= Geometric
    nECoord= -6

    iElt= 3

```

```

EltName= NDfilter_front
Element= Refractor
Surface= Flat
  KrElt= -1.000000000D+22
  KcElt= 0.000000000D+00
  psiElt= 0.000000000D+00 -1.564298529D-01 -9.876890711D-01
  VptElt= 0.000000000D+00 1.901096200D+01 7.336785300D+01
  RptElt= 0.000000000D+00 1.901096200D+01 7.336785300D+01
  IndRef= 1.454853000D+00
  Extinc= 0.000000000D+00
  nObs= 0
  ApType= Circular
  ApVec= 3.000000000D+00 0.000000000D+00 0.000000000D+00
  zElt= 1.000000000D+22
PropType= Geometric
nECoord= -6

  iElt= 4
EltName= NDfilter_back
Element= Refractor
Surface= Flat
  KrElt= -1.000000000D+22
  KcElt= 0.000000000D+00
  psiElt= 0.000000000D+00 -1.564298529D-01 -9.876890711D-01
  VptElt= 0.000000000D+00 1.905007100D+01 7.361477500D+01
  RptElt= 0.000000000D+00 1.905007100D+01 7.361477500D+01
  IndRef= 1.000000000D+00
  Extinc= 0.000000000D+00
  nObs= 0
  ApType= Circular
  ApVec= 3.000000000D+00 0.000000000D+00 0.000000000D+00
  zElt= 1.000000000D+22
PropType= Geometric
nECoord= -6

  iElt= 5
EltName= Cylinder_front
Element= Refractor
EltName= Cylinder
Element= Refractor
Surface= Conic
  fElt= 4.803140000D+00
  eElt= 0.000000000D+00
  KrElt= 4.803140000D+00
  KcElt= 0.000000000D+00
  psiElt= 0.000000000D+00 -1.564298529D-01 -9.876890711D-01
  VptElt= 0.000000000D+00 1.996007600D+01 7.357189100D+01
  RptElt= 0.000000000D+00 1.996007600D+01 7.357189100D+01
  IndRef= 1.512549000D+00
  Extinc= 0.000000000D+00
  nObs= 0
  ApType= Rectangular
  ApVec= -1.250000000D+00 1.250000000D+00 -3.250000000D+00 3.250000000D+00
  zElt= 4.803140000D+00
PropType= Geometric
nECoord= -6

  iElt= 6
EltName= Cylinder_back
Element= Refractor
Surface= Flat
  KrElt= -1.000000000D+22
  KcElt= 0.000000000D+00
  psiElt= 0.000000000D+00 -1.564298529D-01 -9.876890711D-01
  VptElt= 0.000000000D+00 2.018179300D+01 7.497176100D+01
  RptElt= 0.000000000D+00 2.018179300D+01 7.497176100D+01
  IndRef= 1.000000000D+00

```

```

Extinc= 0.000000000D+00
nObs= 0
ApType= Rectangular
ApVec= -1.250000000D+00 1.250000000D+00 -3.250000000D+00 3.250000000D+00
zElt= 1.000000000D+22
PropType= Geometric
nECoord= -6

iElt= 7
EltName= NBPfilter_front
Element= Refractor
Surface= Flat
KrElt= -1.000000000D+22
KcElt= 0.000000000D+00
psiElt= 0.000000000D+00 -1.564298529D-01 -9.876890711D-01
VptElt= 0.000000000D+00 2.065109600D+01 7.793482000D+01
RptElt= 0.000000000D+00 2.065109600D+01 7.793482000D+01
IndRef= 1.454853000D+00
Extinc= 0.000000000D+00
nObs= 0
ApType= Circular
ApVec= 2.000000000D+00 0.000000000D+00 0.000000000D+00
zElt= 1.000000000D+22
PropType= Geometric
nECoord= -6

iElt= 8
EltName= NBPfilter_back
Element= Refractor
Surface= Flat
KrElt= -1.000000000D+22
KcElt= 0.000000000D+00
psiElt= 0.000000000D+00 -1.564298529D-01 -9.876890711D-01
VptElt= 0.000000000D+00 2.068238300D+01 7.813235800D+01
RptElt= 0.000000000D+00 2.068238300D+01 7.813235800D+01
IndRef= 1.000000000D+00
Extinc= 0.000000000D+00
nObs= 0
ApType= Circular
ApVec= 2.000000000D+00 0.000000000D+00 0.000000000D+00
zElt= 1.000000000D+22
PropType= Geometric
nECoord= -6

iElt= 9
EltName= Focal_plane
Element= FocalPlane
Surface= Flat
KrElt= -1.000000000D+22
KcElt= 0.000000000D+00
psiElt= 0.000000000D+00 -1.564298529D-01 -9.876890711D-01
VptElt= 0.000000000D+00 2.101021800D+01 8.020223000D+01
RptElt= 0.000000000D+00 2.101021800D+01 8.020223000D+01
IndRef= 1.000000000D+00
Extinc= 0.000000000D+00
nObs= 0
ApType= Rectangular
ApVec= -1.250000000D-01 1.250000000D-01 -5.900000000D-01 5.900000000D-01
zElt= 1.000000000D+22
PropType= Geometric
nECoord= -6

nOutCord= 5
Tout= 1.000000000D+00 0.000000000D+00 0.000000000D+00 0.000000000D+00
0.000000000D+00 0.000000000D+00 0.000000000D+00
0.000000000D+00 1.000000000D+00 0.000000000D+00 0.000000000D+00
0.000000000D+00 0.000000000D+00 0.000000000D+00

```

	0.000000000D+00	0.000000000D+00	0.000000000D+00	1.000000000D+00
0.000000000D+00	0.000000000D+00	0.000000000D+00		
	0.000000000D+00	0.000000000D+00	0.000000000D+00	0.000000000D+00
1.000000000D+00	0.000000000D+00	0.000000000D+00		
	0.000000000D+00	0.000000000D+00	0.000000000D+00	0.000000000D+00
0.000000000D+00	0.000000000D+00	1.000000000D+00		

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16. Abstract The computer simulation tool, TREETOPS, has been upgraded and used at NASA/MSFC to model various complicated mechanical systems and to perform their dynamics and control analysis with pointing control systems. A TREETOPS model of Advanced X-ray Astrophysics Facility - Imaging (AXAF-I) dynamics and control system was developed to evaluate the AXAF-I pointing performance for Normal Pointing Mode. An optical model of Shooting Star Experiment (SSE) was also developed and its optical performance analysis was done using the MACOS software.					
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